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Exam Preview:

1. According to the local meteorological data, high sustained wind speeds significantly limited flight operations for 5 out of 15 days.
    a. True
    b. False
2. According to the reference material, in 2014, _____ different UAS platforms were available from over 715 global UAS manufacturers
    a. 1,500
    b. 2,000
    c. 2,500
    d. 3,000
3. Using Table 1-1. Generalized differences among basic categories of UAS airframes, what is the estimated platform cost for a small fixed-wing UAS?
    a. $100-$5,000
    b. $1k-$30k
    c. $50-$100k
    d. $10k-$200k+
4. According to the reference material, private industry UAS groups operated under the authority of Title 14 of the Code of Federal Regulations; Part 107 (U.S. Government 2017), which covers use for commercial systems under __ pounds for a variety of activities
    a. 25
    b. 35
    c. 45
    d. 55

5. Hover flights, which are only available to fixed wing aircraft described aircraft traveling to a specific elevation and remaining stationary for an extended time.
    a. True
    b. False
6. Using Table 2-4. Comparative operations specifications for UAS used in the June field experiment, what was the maximum flight time achieved in the study?
    a. 25 mins
    b. 59 mins
    c. 180 mins
    d. 220 mins
7. All flights during the experiment sorted into one of three different categories: hover, canvas, and transect. According to Figure 4-3, 31% of the flights conducted were canvas flights.
    a. True
    b. False
8. Using Table 2-4. Comparative operations specifications for UAS used in the June field experiment, which platform was able to carry 16,000 grams and travel at cruising speeds of 20-30 km/hr?
    a. Reigl RiCOPTER
    b. Sky-watch Cumulus
    c. Multirotor G4 Skycrane
    d. PrecisionHawk Lancaster 5
9. According to the reference material, RGB imagery was by far the most utilized sensor, accounting for over half of the total flight time
    a. True
    b. False
10. Using Figure 4-3. Flight summary statistics from UAS for FRM experiment, and the surrounding material, what percentage of flights were performed by fixed wing type UAS?
    a. 9%
    b. 14%
    c. 45%
    d. 74%

Abstract

The 2017 Duck Unmanned Aircraft Systems (UAS) Pilot Experiment was designed to evaluate existing and new UAS-based survey and monitoring techniques beneficial to U.S. Army Corps of Engineers Flood Risk Management (FRM). The diverse array of UAS sensors (lidar, multispectral packages, and high-resolution cameras) can collect data to estimate topography, bathymetry, terrain, land cover, vegetation, and structures at high temporal and spatial resolution. The experiment took place on 5–24 June 2017 at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Field Research Facility. Nine UAS flight teams from the federal government, academia, and the private sector conducted 180 UAS flights with 10 different UAS platforms as well as 2 traditional fixed-wing plane overhead surveys. The UAS flights combined for over 2,782 minutes of air time across estuarine, dune, beach, and nearshore environments, including various types of natural features and man-made infrastructure. Such datasets provide the foundation for quantitatively comparing the pros and cons of different platforms, sensor packages, and processing techniques against each other as well as traditional survey methods. This special report summarizes the cooperative June 2017 UAS for FRM pilot field experiment; sections detail participating groups, airframes, field preparation/field operations, and data dissemination.

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Preface

This study was sponsored by the U.S Army Corps of Engineers (USACE) Flood and Coastal Systems Research and Development (F&C) Program and the Coastal and Ocean Data Systems (CODS) Program, under the Unmanned Aircraft Systems Support to Flood Risk Management work unit.

This report was prepared by the Coastal Observations and Analysis Branch (CEERD-HFA) of the Flood and Storm Protection Division (CEERD-HF), U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). The F&C Program is administered under the Flood Risk Management (FRM) Business Line of Headquarters, USACE (HQUSACE). Mr. Mark Roupas (HQUSACE) was FRM Business Line Manager overseeing F&C. Dr. Julie D. Rosati was the Technical Director of the FRM R&D Programs, and Dr. Jeffrey P. Waters was Program Manager of the CODS. CODS is administered at ERDC CHL with funding from the HQUSACE Navigation Business Line. At the time this effort was conducted, Ms. Sheryl A. Carrubba was the acting Navigation Business Line Manager overseeing the CODS Program. Mr. W. Jeff Lillycrop was the ERDC Technical Director for Civil Works and Navigation Research Development and Technology.

Technical reviews and discussions of this report were provided by Ms. Jennifer G. Laird of ERDC Environmental Laboratory and Mr. Victor L. Wilhelm of USACE, Jacksonville District.

At the time of this publication, oversight and guidance of this work was provided by Dr. Jeffrey P. Waters, Chief, Coastal Observations and Analysis Branch, and Dr. Cary A. Talbot, Chief, Flood and Storm Protection Division.

Dr. Jacqueline S. Pettway was the acting Deputy Director of CHL, and Mr. Jeffrey R. Eckstein was the acting Director.

The Commander of ERDC was COL Bryan S. Green, and the Director was Dr. David W. Pittman.

Abbreviations

3D	three-dimensional
CEERD-HF	U.S. Army Corps of Engineers, Engineer Research and Development Center, Flood and Storm Protection Division
CEERD-HF-A	U.S. Army Corps of Engineers, Engineer Research and Development Center, Flood and Storm Protection Division, Coastal Observations and Analysis Branch
CHL	Coastal and Hydraulics Laboratory
CLARIS	Coastal Lidar and Radar Imaging System
CONOPS	concept of operations
CRREL	Cold Regions Research and Development Laboratory
DEM	digital elevation model
EL	Environmental Laboratory
ERDC	U.S. Army Engineer Research and Development Center
FAA	Federal Aviation Administration
FRM	Flood Risk Management
FRF	Field Research Facility
ft	foot/feet
g	gram
GCP	ground control point
GPS	Global Positioning System
GRL	Geospatial Research Laboratory
Hz	hertz
IA	Infrastructure Area
IMU	inertial measurement unit
IR	infrared radiation
JALBTCX	Joint Airborne Lidar Bathymetry Center for Expertise
km	kilometers

LARC	Lighter Amphibious Resupply Cargo
m	meters
mHz	megahertz
min	minute(s)
m/s	meters per second
NAVD88	North American Vertical Datum of 1988
NGA	National Geospatial-Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
PI	Principal Investigator
R&D	Research and Development
RAID	Redundant Array of Independent Disks
RGB	red-green-blue
RTK-GPS	Real-Time Kinematic Global Positioning System
SC	Santa Cruz, CA
SfM	structure from motion
SP	St. Petersburg, FL
TB	terabyte
TCV	Top Cover of Virginia
TDS	THREDDs Data Server
THREDDS	Thematic Real-time Environmental Distributed Data Services
UAS	Unmanned Aircraft Systems
USACE	U.S. Army Corps of Engineers
UAS for FRM	Unmanned Aircraft Systems for Flood Risk Management
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VCU	Virginia Commonwealth University
VIP	very important person
WH	Woods Hole, MA

1 Introduction

1.1 Purpose

This special report summarizes a pilot field experiment that took place in June 2017 at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Field Research Facility (CHL-FRF), during the first year of a new work unit entitled "Unmanned Aircraft System[1] (UAS)[2] Support to Flood Risk Management (FRM)." The purpose of this report is therefore to (1) document the occurrence and goals of the experiment; (2) to serve as a reference document for what data sets were collected and by whom; and (3) to provide lessons learned for others interested in developing similar experiment plans. Sections detail the field experiment preparation, participating teams, and types of airframes operated. While the data collection, aggregation, and dissemination are described in this report, the data processing and experimental results will be presented in future publications.

1.2 Background

1.2.1 Flood Risk Management (FRM) Research and Development (R&D) needs

The combination of human development and static infrastructure with the dynamic and diverse landscapes of coastal and riverine environments creates management challenges for navigation, storm damage reduction, and ecosystem health that are exacerbated during natural disasters. The U.S. Army Corps of Engineers (USACE) FRM mission strives to reduce the nation's flood risk and increase resilience to disasters. FRM is inherently interdisciplinary, requiring accurate identification of environmental, physical, and infrastructure features that can reduce risk from flood and coastal storm disasters. The ERDC continues to focus on providing tools for USACE and its partners that enable data-driven decision-making and management.

The ERDC *Research & Development Strategy for Flood Risk Management* (2015) identifies a number of R&D opportunities to reduce

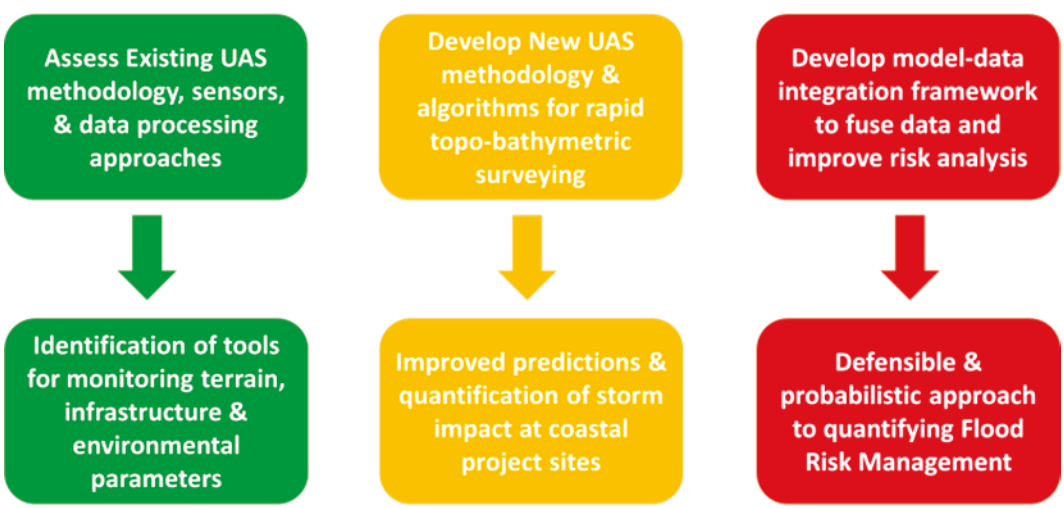
[1] *Unmanned Aircraft System* may also be referred to as *Unmanned Aerial Systems*.

[2] In this report, the abbreviation *UAS* is considered both singular and plural.

disaster risks, which include (1) identifying better technologies for hazard identification pre- and post-events; (2) developing an interdisciplinary understanding of physical, chemical, and biological recovery processes that occur post-event; and (3) providing shared and easily accessible, up-to-date data sets that can be utilized by flood and coastal storm modeling and predictive tools to inform emergency response. Cost-efficient technology and methodology, such as the use of UAS, that allows for accurate, detailed, and timely two-dimensional and three-dimensional (3D) monitoring of coastal and riverine landscapes have the potential to address many of these goals. Adapting new technologies demands an understanding of existing methods, identifying gaps or short-comings with current techniques, and then developing new approaches and providing guidance and insight on how new tools can address these gaps as well as exploring potential future capabilities.

Given the potential for UAS to be applied to FRM, the ERDC Flood and Coastal Systems Program, Coastal and Ocean Data Systems Program, and Field Data Collection Program have initiated an effort to identify and develop defendable and consistent UAS-based methodologies and data products that can seamlessly integrate with numerical models to improve quantification of the nation's flood risks to the coastal and riverine shorelines, infrastructure, ecosystems, and communities. The objectives and expected products to assess UAS-based FRM, presented in Figure 1-1, require an evaluation of data collection and processing approaches for different UAS.

Figure 1-1. Unmanned Aircraft Systems Support to Flood Risk Management (UAS for FRM) objectives (top row) and expected products (bottom row).



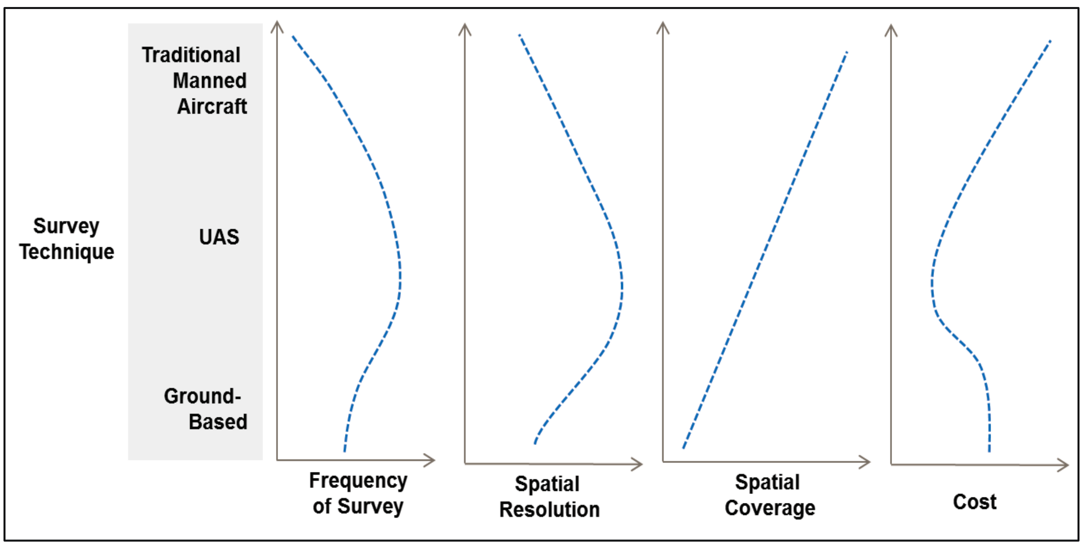
1.2.2 Unmanned Aircraft Systems (UAS) – A new FRM tool

The Federal Aviation Administration (FAA) defines a UAS as an "unmanned aircraft and its associated elements (including communication links and the components that control the small unmanned aircraft) that are required for the safe and efficient operation of the small unmanned aircraft in the national airspace system,"based off of Title 14 of the Federal Code of Regulations, Part 107 – Small Unmanned Aircraft Systems (FAA 2018; U.S. Government 2017). As UAS responsiveness, flexibility, affordability, and operability have improved, the door has been opened for a wide variety of different remote sensing applications, including FRM (Karaağaç et al. 2015; Klemas 2015). The growth in number of platforms and technology development has only accelerated over the past decade. The global number of referenced UAS initiatives across the globe more than tripled from 2005 to 2013, as different military, research, and civil/commercial UAS applications developed (Colomina and Molina 2014). The growing industry continues to increase the number of UAS platforms to choose from. In 2014, 2,500 different UAS platforms were available from over 715 global UAS manufacturers (Cress et al. 2015). Colomina and Molina (2014) state that the trend has been especially strong for remote sensing applications and will only continue to develop in the future. Along with the benefits more choices bring, the differences in data quality, efficiency, and cost also demand increasing effort to identify and evaluate the most applicable technologies.

UAS have already proven valuable to different types of public safety and crisis applications, ranging from search-and-rescue operations to earthquake response to fighting forest fires (Waharte and Trigoni 2010; Xu et al. 2014; Merino et al. 2012). Public flood response has already been improved by these technologies in certain circumstances across the globe. During flooding in the Balkans in 2014, UAS use generated significant time savings, critical to life-and-death scenarios (De Cubber et al. 2014). In China, a UAS was used to successfully map and assess urban flooding conditions (Feng et al. 2015). Besides active response, government agencies have begun to shape proactive management strategies by deploying UAS for efficient survey and assessment of natural resources and infrastructure (Cress et al. 2015). These evaluations have ranged from dams and penstocks to earthquake-damaged buildings to bridge inspections using infrared (IR) cameras (Özaslan et al. 2015; Michael et al. 2012; Khan et al. 2015). The UAS for FRM work unit has looked to develop the equivalent technology and approaches to enhance USACE FRM efforts.

By providing high-resolution spatial data captured at low altitudes, UAS technology may fill the gap between traditional ground and high-altitude surveying for FRM (Figure 1-2). For example, Feng et al. (2015) have stressed the ability of UAS to operate when other remote sensing techniques may be limited by cloud cover or other climatic conditions. As Figure 1-2 illustrates, these potential benefits come at a relatively lower cost, likely requiring fewer resources than the man hours required to cover the same amount of area on the ground or infrastructure to launch a plane for that particular task. UAS methods can facilitate coverage of FRM-relevant areas that are difficult to access by ground crews, such as the surf-zone, flooding rivers, elevated or compromised infrastructure, or protected ecosystems. Given their remote operation and maneuverability, UAS provide this access during high-risk scenarios with minimal risk to human life or infrastructure (Ma et al. 2013).

Figure 1-2 Potential for UAS to fill the gap between ground-based surveys and traditional manned aircraft.



UAS benefits to FRM may also demand less preparation or deployment time and investment than traditional methods. Therefore, survey frequency could be increased, as suggested by Figure 1-2. UAS monitoring could provide more interim evaluations of shore-protection infrastructure and reduce the number of data gaps witnessed when evaluating damage from extreme events similar to Hurricane Sandy (USACE 2013). Facilitating data collection may therefore capture and support the kinds of rapid pre-storm assessments and short-term forecasting necessary for an improved data assimilation effort.

While an increasing number of UAS variations exist (e.g., Figure 1-3), the types of UASs that may be able to support USACE FRM may still be placed into several basic categories. Most UAS airframes are either fixed-wing or multirotor airframes, equivalent to an airplane or a helicopter. While a multirotor UAS platform may be more maneuverable (e.g., less take-off area clearance required, ability to hover in place), fixed-wing platforms often have longer maximum flight potential (see Table 1-1). The development of vertical takeoff and landing (e.g., BirdsEyeView FireFLYPro6) attempts to combine the benefits of both by rotating its rotors angles between take-off/landing and flight modes. Advanced Global Positioning System (GPS) and inertial measurement units (IMU) have further streamlined UAS maneuverability and navigation precision of both types as well. By allowing pilots to pre-plan waypoints and flight plans, automation can enhance airtime efficiency and reduce data collection error.

Figure 1-3. Different UAS platforms flown at the June Duck Pilot UAS for FRM Field Experiment. By column, left to right (3DR X8+, SenseFly eBee, DJI Phantom 4 Pro, BirdsEyeView FireFLY6 Pro, DJI Matrice 100, Multirotor G4 Skycrane, Riegl RiCopter, Sky-watch Cumulus, 3DR Solo, PrecisionHawk Lancaster.

As evident in Table 1-1, more sophisticated platforms provide more capabilities, but these abilities often relate to the airframe price and required piloting skills. Lower-priced, consumer-oriented platforms remain more constrained to basic red-green-blue (RGB) cameras while more modular UAS developer airframes (e.g., 3DR X8+) may provide more flexibility in sensor adjustment. Some of the most sophisticated (and highest-priced) platforms integrate instrument packages that bind airframes, sensors, and navigation tightly together for one principal data objective (such as operating a lidar scanner from the Riegl RiCopter).

Table 1-1 also shows that platform complexity is associated with platform payload weight. Extra capacity allows for UAS to incorporate more powerful sensors instruments as well as the capacity to combine several into integrated sensors packages.

Table 1-1. Generalized differences among basic categories of UAS airframes.

	Small multi-rotor	Large multi-rotor	Small fixed-wing	Mid-size fixed-wing
Platform Cost	$100 - $5000	$50 – 100K+	$1K - $30K	$10K – 200K+
Flight Time	10 – 30 min	30 min – 1 hr	20 min – 3 hrs	1 – 24 hrs
Payload Weight	0.5 – 1 kg	5 – 15 kg	0.25 – 2 kg	0.5 – 5 kg
Complexity	Minimal	High	Moderate	Very High
Skill Level	Minimal	High	Moderate	High
Takeoff	Vertical	Vertical	Hand/launcher /vertical	Launcher/ runway

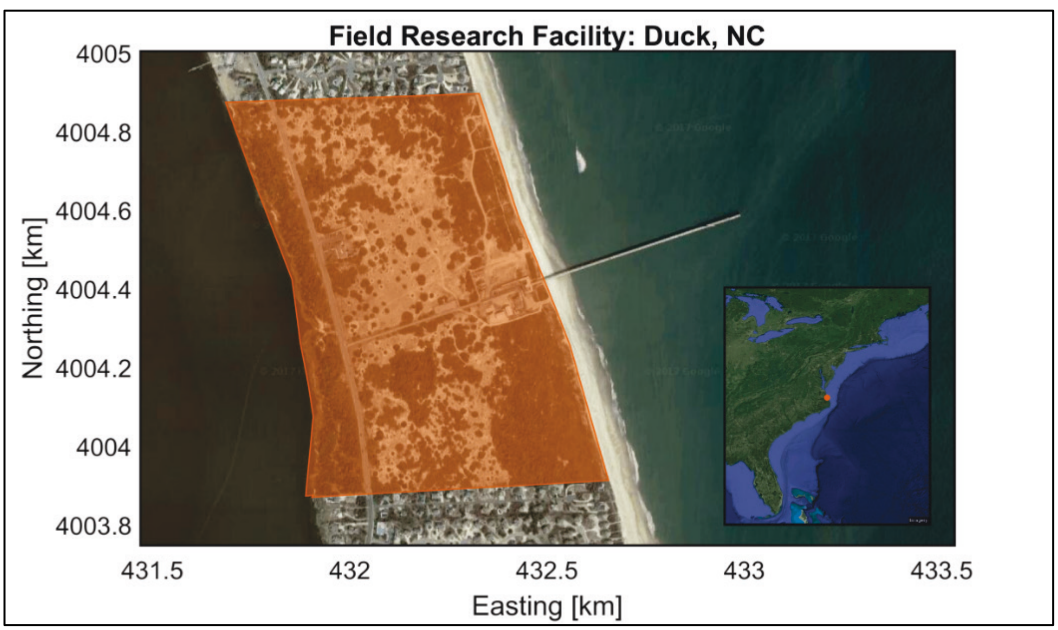
UAS instrumentation can range from consumer cameras to platform-designed lidar scanners (see Tables 2-1, 2-2, 2-3 for examples of sensors used in this experiment). Various sensor packages, or combinations thereof, provide different methods of directly and indirectly quantifying geospatial features (bathymetry, topography), critical aspects of infrastructure and environmental health.

For example, to assess flood-vulnerable terrain, digital elevation models might be generated using lidar point clouds or high-resolution RGB camera data. In addition, a variety of processing software packages and methodologies are commercially and openly available that can process camera imagery into data products. With multiple platforms, concept of operations (CONOPS), sensor packages, and software, there are a multitude of options with varying accuracies available to USACE. To help USACE determine the most effective UAS system for specific research goals and data requirements, a field experiment was coordinated to evaluate the effectiveness of different UAS systems in achieving common USACE research questions.

1.3 Approach

Evaluating and developing UAS data collection and processing approaches demands a significant field deployment effort. The field experiment at CHL-FRF took place over 3 weeks in June 2017 and aimed to advance current efforts to identify applications of existing UAS technology, develop rapid topo-bathymetric survey approaches, and fuse data from different sources in model-data integration frameworks. The CHL-FRF is located in Duck, NC, a town in the northern portion of the Outer Banks, and is bounded by the Atlantic Ocean to the east and Currituck Sound to the west (Figure 1-4). The facility's setting allowed for evaluating different UAS-based sensors in surf-zone, beach, dunes, barrier island, marsh, and estuarine environments. Constructed targets, a mock jetty, and ground control points (GCPs) allowed for assessing UAS approaches to identify movement and deterioration of coastal structures. CHL-FRF provided additional surveys and data records to further contextualize the collection effort. These included weekly terrestrial lidar and bathymetric surveys that allowed UAS data to be calibrated against traditional data as well as against each other.

Figure 1-4. Map of FRF (UTM[1]-18N) with the property boundary in orange. Inset: FRF location on U.S. East Coast. (Satellite imagery courtesy of Google Earth.)



[1] Universal Transverse Mercator

During the experiment, 11 flight teams from ERDC labs, other federal government agencies, private industry, and academia flew 12 different airframes (See Section 2). Nine of these teams flew UAS platforms while two teams flew traditional manned platforms to add to the collection of data types. To participate, the flight teams were required to share their data with the rest of the experiment participants via a central data repository. The final aggregated data generated over 180 flights and make up a unique and comprehensive UAS dataset. By inviting a large number of different teams to collect data at the same location and same time period, the UAS for FRM initiative can examine different UAS technologies using the same data sources. With the diverse array of flight patterns, platforms, sensors, and processing software utilized at the experiment, USACE can assess data products without one organization having to purchase and train with each individual technology. Operators were requested to fly their typical CONOPS for their platform/sensor to maximize the strengths of each approach and enable a practical comparison amongst the different methods. The goal of the project was to assess UAS systems for typical USACE FRM efforts, not to require artificially constructed CONOPS.

While the pilot field experiment data could be utilized for a number of different applications, these data were chiefly collected to support USACE FRM efforts. The data will allow ERDC to evaluate how well different platforms and sensors are able to quantify terrain, surf-zone bathymetry and hydrodynamics, infrastructure condition, as well as environmental parameters. Specifically, ERDC will investigate the quality (accuracy and resolution) of topographic and bathymetric digital elevation models (DEMs), the accuracy of surf-zone surface current and wave runup observations, and the ability to detect edges and movement in coastal infrastructure. From the environmental perspective, the experiment supported efforts to classify vegetation species, distribution, and associated landscape metrics that help characterize the ecological health involved with FRM. This analysis will require evaluation and development of processing software that efficiently develops the raw data into products. Future efforts will also develop approaches to integrate the UAS data with numerical models to improve risk analysis with a defensible, probabilistic approach.

This special report summarizes the preparation and execution of the pilot field experiment. Chapter 2 lists data collection goals and UAS platforms for each participating team. Chapter 3 provides field site information such as available ground control data, meteorological conditions, and aviation awareness. Chapter 4 summarizes data collection efforts. Chapter 5 describes experiment data aggregation and dissemination. The report concludes with Chapter 6, an evaluation of the field experiment and future work.

2 Participation

2.1 Call for participation

The success of the UAS for FRM summer experiment demanded the operation of a diverse assortment of UAS platforms and sensors to compare different UAS approaches to data collection, more so than ERDC-CHL could hope to accomplish alone.

Coordination began through the project's principal investigators, which included members from CHL, the Environmental Laboratory (EL) and Geospatial Research Laboratory (GRL). The ERDC Cold Regions Research and Development Laboratory (CRREL) and the Joint Airborne Lidar Bathymetry Center for Expertise (JALBTCX) were also invited to support the data collection aspects of the experiment. Following internal organization, the formal invitation was extended to external coastal and remote sensing colleagues and partners in April of 2017 with the hope that the ERDC lab flight teams would be joined by other government agencies and private industry partners, as well as academics.

Participants had to demonstrate that they were prepared to fly legally and had to be prepared to provide the appropriate agency/organization documentation of clearance to fly. Government operators needed to have their Certificates of Waiver or Authorization specific to the activity, as well as Airworthiness Release certifications for ERDC labs to prove that their UAS airframes are fit to fly (FAA 2017; U.S. Army 2016). Private industry groups operated under the authority of Title 14 of the Code of Federal Regulations; Part 107 (U.S. Government 2017), which covers use for commercial systems under 55 pounds for a variety of activities (FAA, OST, and DOT 2015).

The other chief requirement for UAS teams interested in joining the experiment was their willingness to share their data collected in June with the rest of the community. In exchange for the data contribution, flight teams were given the opportunity to test their platforms over ideal, undeveloped, and unpopulated terrain. The teams were also provided, free of charge, with a number of control datasets collected by CHL-FRF.

2.2 Participants

Eleven different flight teams flew as part of the June experiment, with a few of the teams integrating team members from different partner organizations. Nine of these teams flew UAS platforms (Tables 2-1, 2-2), while two teams flew manned fixed-wing platforms (Table 2-3) to increase the range of collected data types.

Table 2-1. Multirotor airframes operated at the UAS for FRM June experiment. U.S. Geological Survey (USGS) labeled as Santa Cruz (SC) and Woods Hole (WH) teams. ERDC laboratories: EL, CHL, CRREL

Multirotor UAS Airframe		Instruments	Operator
	Multirotor G4 Skycrane	Velodyne HDL 32E, Map IR Survey 2, Headwall Nano-Hyperspectral Imager	ERDC-EL
	Riegl RiCopter	Riegl VUX-1LR scanner w/Applanix AP20 IMU + Sony Alpha 6000 (x2)	ERDC-CRREL
		Adjusted Riegl RiCopter; Riegl BDF-1	ERDC-CRREL/Riegl
	3DR X8+	MVSS (custom GoPro Hero4 synced)	ERDC-CHL
	DJI Phantom 4 Pro	stock 24mm 20MP DJI camera (4K)	ERDC-CHL
	DJI Matrice 100	Zenmuse XT (Flir Tau 2)	ERDC-CHL
		Zenmuse X5 (RGB) converted X5 (BRNIR)	PrecisionHawk
	3DR Solo	Ricoh GRII RGB Camera; MicaSense RedEdge Multispectral	USGS-WH
		GoPro Hero 4 (Peau Productions lens reduces barrel distortion)	USGS-SC
		Sony R10C Camera	VCU

Table 2-2. Fixed-wing platforms and operators at the UAS for FRM.

Fixed-Wing/VTOL UAS Airframe		Instruments	Operator
	Sensefly eBee (& eBee plus RTK)	Canon S110, CIR, Thermomap, Sequoia multispectral	ERDC-GRL/ NOAA
		RTK + EO cameras, SenseFly SODA	VCU
	Sky-Watch Cumulus	Sony RX100	VCU
	BirdsEyeView Aeronautics FireFLY6 Pro	Sony a6000, Sony a7R	BirdsEyeView Aeronautics
	PrecisionHawk Lancaster 5	Velodyne Puck, MicaSense MSI	PrecisionHawk

Table 2-3. Manned flight data collection over FRF property. USGS-SP and USGS-WH refer to USGS offices in St. Petersburg, FL, and Woods Hole, MA, respectively. WMR-532 is a contractor operator.

Manned Aircraft		Instruments	Operator
	Rhiems/ Cessna 406	Lidar: Coastal Zone Mapping and Imaging Lidar; Leica RCD30 60megapixel RGBN Aerial Camera; Hyperspectral ITRES CASI-1500 Camera	JALBTCX/ WMR-532
	Cessna 182	Nikon D810, Nikkor50mm F1.8 prime lens	USGS-SP/USGS-WH/Top Cover of Virginia

2.2.1 U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL)

- Team: Kate Brodie, Nick Spore, Brittany Bruder, and Alex Renaud
- Airframes: 3DR X-8+ with Multi-View GoPro System and DJI Phantom 4 Pro
- Data Collection Goals: Capture coastal topography, bathymetry, surf-zone hydrodynamic data, and conduct FRM structure assessment. Testing particularly focused along the beach and inner compound area and included partnering with other teams to test different platform

performance for factors such as oblique angle flights offshore and sea-surface imagery captured from different altitudes.

2.2.2 ERDC Geospatial Research Laboratory/National Oceanic and Atmospheric Administration (GRL/NOAA)

- Team: Rob Fischer, Jason Woolard (NOAA), Jarrod Edwards, Krystle Miner, Mike Campbell, and Matt Voss.
- Airframes: SenseFly eBee
  Data Collection Goals: Terrain mapping, coastal topography, and infrastructure assessment, including thermal images/videos. Given partnership and collaboration and use of the same platform, GRL and NOAA shared the same eBee for flight operations and data collection. GRL conducted detailed ground terrain and structure surveying in addition to flight operations.

2.2.3 ERDC Environmental Laboratory (EL)

- Team: Molly Reif, Shea Hammond, Kenneth Matheson, Safra Altman, Sean Melzer, J. Heath Harwood
- Airframes: Multirotor G4 Skycrane
- Data Collection Goals: Test lidar and multispectral packages ability to capture topography, map and characterize vegetation, land cover, and assess infrastructure. As part of flight crew, ground crew set additional targets to support sensor packages and characterize vegetation by hand.

2.2.4 ERDC Cold Regions Research and Engineering Laboratory (CRREL)

- Team: Adam LeWinter, David Finnegan, Scott Simper, Peter Gadomski, Charlie Kershner (National Geospatial-Intelligence Agency [NGA]), Mike Aslaksen (NOAA), Darren Hauser (National Center for Airborne Laser Mapping), Andrés Vargas (Riegl USA, Inc.)
- Airframes: Riegl RiCOPTER with VUX-1UAV Lidar sensor and Riegl BDF-1 bathymetry profiler (sensors interchangeable)
- Data Collection Goals: Capture coastal topography and bathymetry and conduct FRM structure assessment. Test different lidar sensors and acquisition parameters for best operational performance and inform future research directions.

2.2.5 U.S. Geological Survey (USGS) - Woods Hole

- Team: Sandra Brosnahan, Chris Sherwood
- Airframes: 3DR Solo
- Data Collection Goals: Focused on structure from motion (SfM), testing multispectral data collection, and comparing standard mapping flow with other approaches.

2.2.6 U.S. Geological Survey (USGS) - Santa Cruz

- Team: Shawn Harrison
- Airframes: 3DR Solo
- Data Collection Goals: Focus on optimizing video data collection strategy for estimating nearshore bathymetry (via the bathymetric inversion algorithm Bathy), including how to best assist filtering for combining multiple collections, the impact of camera viewing angle relative to the direction of wave propagation, and determining survey coverage limitations.

2.2.7 Virginia Commonwealth University/GRL

- Team: Will Shuart, Rob Fischer (GRL)
- Airframes: SenseFly eBee, Sky-watch Cumulus One, 3DR Solo
- Team FRM Applications: Testing different platforms and sensors for image capture and terrain mapping, including real-time kinematics global positioning system (RTK-GPS), surveying capabilities, as well as an SfM data collect.

2.2.8 BirdsEyeView Aerobotics

- Team: Nate Miller, Rene Roy
- Airframes: FireFLY6 Pro
- Data Collection Goals: Testing of RTK-GPS release with platform by gathering further validation data to inform operational capabilities and applications.

2.2.9 PrecisionHawk

- Team: Nate Lamonds, Matt Wallace, Kelsey Adkins, Blaine Horner
- Airframes: Lancaster 5, DJI Matrice 100
- Data Collection Goals: Deploying fixed-wing airborne lidar as well as supporting processing and data application with principle platform.

2.2.10 ERDC Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX)

- Team: WMR-532, JALBTCX, Chris Macon
- Airframe: Rhiems/Cessna 406
- Data Collection Goals: Extension of regional coastal survey and mapping in area to include FRF property, along with several cross-check flights.

2.2.11 USGS St. Petersburg/USGS-Woods Hole/Top Cover of Virginia (TCV)

- Team: Karen Morgan (USGS sponsor), Chris Sherwood (USGS sponsor), Carol McManus (TCV), Lee McManus (TCV)
- Airframes: Cessna 182
- Data Collection Goals: Capture traditional aerial photography of entire FRF property to allow comparison to standard photogrammetric techniques from higher altitude.

2.3 UAS platform comparison

UAS platforms utilized in the experiment ranged in design, size, and operational specifications. Differing flight specifications may support the use of one platform in certain conditions while requiring another in others (e.g., desired flight time, spatial coverage, available payload). The following table lists basic parameters for UAS platforms flown during the June pilot experiment. Data represent ideal conditions and sensor payload weights.

Table 2-4. Comparative operations specifications for UAS used in the June field experiment. Specifications are principally from manufacturer websites/manuals. Comparison is likely approximate given different manufacturer definitions.

UAS Platforms	Approx. Max. Flight Time (min)[1]	Max. Payload (g)[2]	Trans-mission Range (km)[3]	Max. Speed (km/hr)[4]	Cruise Speed (km/hr)	Wind Stable Limit (km/hr)	Approx. Price ($USD)[5]
3DR Solo	25	420	0.8	89		40	<5K
3DR X8+	15	800	1	40	23	40	5 – 50K
DJI Phantom 4 Pro	30		7	72		36	<5K
DJI Matrice 100	40	1200	5	79		36	<5K
Multirotor G4 Skycrane	12	6,500	2+	40 - 50		36 - 54	<200K

UAS Platforms	Approx. Max. Flight Time (min)[1]	Max. Payload (g)[2]	Trans-mission Range (km)[3]	Max. Speed (km/hr)[4]	Cruise Speed (km/hr)	Wind Stable Limit (km/hr)	Approx. Price ($USD)[5]
Reigl RiCOPTER	30	16,000	1	60	20-30	30	<200K
FireFLY6 Pro	40-50	700	5+	65	54 - 65	37	5 – 50K
Sky-watch Cumulus	180	600			58	36	5 – 50K
PrecisionHawk Lancaster 5	45	1,150	2	79	43 - 58	36	5 – 50K
SenseFly eBee	50	150	3	90	40 - 90	43	5 – 50K
SenseFly eBee Plus	59	300	8	110	40 - 110	43	5 – 50K

[1] minute
[2] gram
[3] kilometer
[4] kilometer/hour
[5] Basic price estimates, given high variability due to sensors and associated software.

2.4 Technical demonstration

In an effort to inform potential stakeholders and receive feedback, key USACE personnel from Headquarters, USACE and ERDC were invited to participate in a very important person (VIP) day on Thursday, June 22. VIPs learned about the work unit overall scope and the potential for UAS applications to flood risk management. Besides hearing initial results from the experiment principal investigators (PIs), VIPs also were provided with live demonstrations of different ERDC lab-operated platforms across different areas of the FRF.

VIPs expressed encouragement over the work done so far and the methodological experiment design. Given the need to keep up with a sloping technology front, this work should continue to be conducted into the future. As the work unit moves towards helping tie data collection to FRM decision-making, participants also stressed the benefits of continuing to consider the end goals of informing UAS use in certain scenarios. This experiment and the associated work unit should especially serve to help districts as they begin their own UAS development and deployment. Just as this information can inform districts, UAS research can also work towards mimicking certain district operational approaches to best align the two in the future. Finally, ERDC VIPs and the UAS team discussed the benefits of USACE leaders helping researchers navigate current rules and regulations as this technology is developed and deployed in the future.

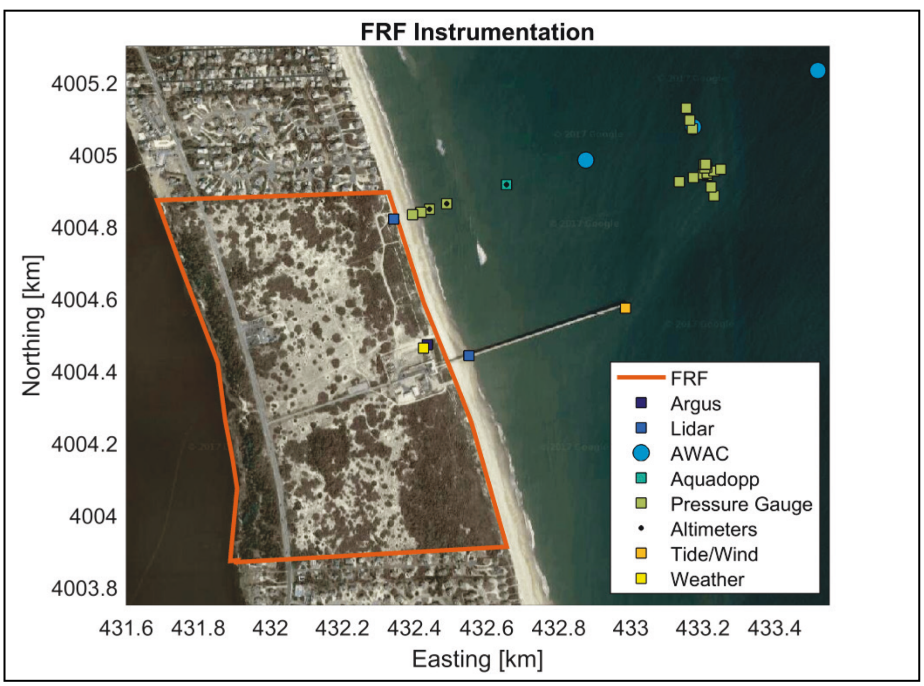
3 Field Site and Control Data

The experiment took place at the FRF, a coastal observatory operated and maintained by the ERDC-CHL Coastal Observations and Analysis Branch near Duck, NC. Field preparations for the experiment included (1) identifying regions of ecological and geomorphic interest; (2) charting flight lines and takeoff positions with respect to these areas; (3) constructing and installing targets for ground control and point cloud product evaluation; (4) surveying targets, topography, and bathymetry; (5) planning for and monitoring meteorological conditions; (6) as well as clearing airspace for UAS activity. In this chapter, each preparation is described in detail as well as the field site itself.

3.1 Field site

The FRF, situated on the Outer Banks of North Carolina, encompasses 175 acres near the town of Duck, NC (Figure 3-1). The FRF main feature is its 560-meter (m)-long research pier extending out into the Atlantic Ocean. The facility has maintained continuous observation and measurement of oceanographic, meteorological, and morphological processes in the offshore and nearshore environments since 1977 (Birkemeier et al. 1985).

Figure 3-1. Map of FRF and in situ instrumentation (UTM-18N). WaveRider bouys not shown. (Satellite imagery courtesy of Google Earth.)



The facility operates two instrument arrays to observe waves, currents, seafloor elevation, and water level from the continental shelf to the swash zone (Bak et al. 2017; Hanson et al. 2009; Long and Oltman-Shay 1991). The cross-shore array, detailed in Table 3-1 (A) and displayed in Figure 3-1, is located 400 m north of the research pier. Another array of 15 pressure sensors operates at the 8 m contour approximately 900 m from the shoreline to provide wave direction information (Figure 3-1; Table 3-1). At the seaward end of the pier, NOAA Tidal Station 8651370 provides an additional acoustic water level measurements (NOAA 2017). All the FRF in situ measurements are necessary to evaluate the accuracy of hydrodynamic and bathymetric estimates calculated from the collected UAS data.

UAS estimates and imagery will also be evaluated against products derived from the 43 m tall Argus tower on site (Figure 3-1, Table 3-1 (B)). As part of the Argus network, the six-camera system produces geo-rectified images of the coastline and associated data products every half-hour (Holman and Stanley 2007). Image products are produced from a 10 min collection at 1 hertz (Hz) and include time-averaged (Figure 3-2), maximum/minimum, and variance of pixel intensities that can provide shoreline and sandbar position estimates. Along with cBathy algorithms, the 1 Hz snapshots produce bathymetry estimates (Holman et al. 2013). Timestacks, created from concatenated cross-shore pixel arrays from each snapshot, provide wave run-up speed and swash excursion estimates. UAS can also produce these image products and associated estimates (Holman et al. 2017).

Figure 3-2. Example image product from FRF Argus tower during experiment. Time-averaged pixel intensity shown for 9 June 2017 15:30:01 GMT. *X*- and *Y*-axes are in meters.

Table 3-1. Fixed oceanographic and morphologic instrumentation at FRF.

(A) In Situ Sensors					
Instruments	**Observation Type**	**Latitude**	**Longitude**	**Nominal Depth**	**Report Interval**
Datawell WaveRider Buoy	30 min directional wave and current statistics	36.25867	-75.59217	26 m	30 min
		36.20017	-75.71533	17 m	
Nortek AWAC	34 min directional wave and current statistics	36.18961	-75.73940	11 m	60 min
		36.18818	-75.74323	8 m	
		36.18733	-75.74654	6 m	
Nortek Aquadopp & Altimeter	34 min directional wave, current, and bed elevation statistics	36.18670	-75.74898	3.5 m	60 min
Paroscientific Pressure Gauge and Acoustic Altimeter	34 min directional wave and bed elevation statistics	36.18621	-75.75082	2.8 m	60 min
		36.18607	-75.75135	2.1 m	
Paroscientific Pressure Gauge	34 min directional wave statistics	36.18599	-75.75162	1.9 m	60 min
		36.18593	-75.75187	0.75 m	
AquaTrak Air Acoustic Sensor (NOAA Station)	Water level	36.18333	-75.74667	N/A	6 min
Senso-Metric Pressure Gauge	60 min directional wave statistics	36.1864616	-75.7425750	8 m	60 min
		36.1866799	-75.7426690	8 m	
		36.1869757	-75.7427900	8 m	
		36.1869993	-75.7429120	8 m	
		36.1869112	-75.7432144	8 m	
		36.1868046	-75.7436517	8 m	
		36.1870246	-75.7427930	8 m	
		36.1870770	-75.7425835	8 m	
		36.1871292	-75.7423697	8 m	
		36.1871703	-75.7428053	8 m	
		36.1871544	-75.7428605	8 m	
		36.1872375	-75.7428906	8 m	
		36.1881327	-75.7432552	8 m	
		36.1883522	-75.7433438	8 m	
		36.1886457	-75.7434516	8 m	
		36.1872500	-75.7428410	8 m	

(B) Argus Tower					
Observation Type	Report Interval	Minimum Azimuthal Resolution	Latitude	Longitude	Nominal Elevation
Geo-rectified Imagery	30 min	0.25pixels/m at 500m tower radius	36.18268	-75.75138	43 m

(C) Terrestrial Lidar Scanner					
Instrument	Latitude	Longitude	Horizontal (Φ) and Vertical (Θ) Scan Angular Resolution	Measurement Type	Report Interval
Dune Riegl VZ-1000 lidar	36.1858274	-75.7524535	Transect: Θ=0.025° 3D Scan: Φ=0.04° Θ=0.02°	Cross-shore elevation transects 30 min at 7 Hz	60 min
				3D Pointcloud	
Pier Riegl Z390i lidar	36.1824197	-75.7500835	3D Scan: Φ=0.02° Θ=0.03°	3D Pointcloud	60 min

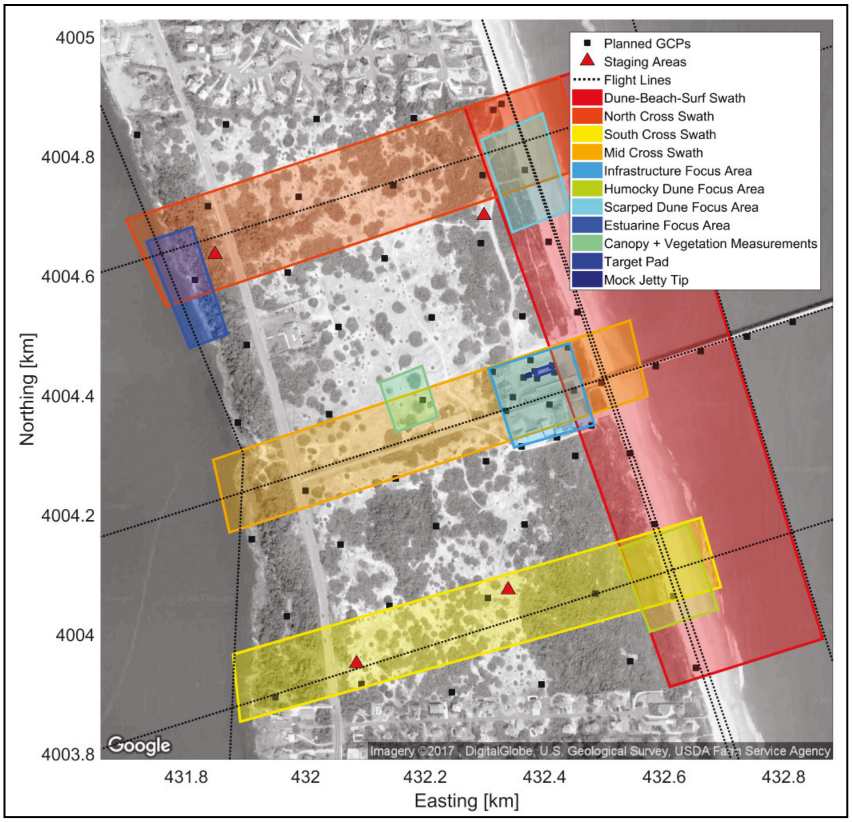
A dune-mounted terrestrial lidar scanner complements the Argus shoreline estimates (Figure 3-2, Table 3-1 (C)). The Riegl VZ-1000 scanner records elevation transects across the swash and inner surf-zone continuously at 7 Hz for 30 min every hour, allowing for additional wave, run-up, and swash zone topography estimates along the cross-shore array[1] (Brodie et al. 2015). In addition, the lidar performs a 3D scan every hour to provide dune and sub-aerial foreshore topography point clouds in a 600 m radius. An additional Riegl Z390i terrestrial lidar scanner observes dune and beach topography closer to the research pier. (Figure 3-1; Table 3-1 (C)). Analysis for this experiment will compare point clouds from these fixed-mounted scanners with those derived from UAS imagery or lidar observations.

3.2 Areas of interest and proposed flight lines

The FRF is ideal for the UAS for FRM experiment not only because of its extensive instrumentation but also due to the variety of coastline morphology and ecology (Figure 3-3). Bordered by the Atlantic Ocean and Currituck Sound, the experiment can evaluate the effectiveness of UAS as an FRM tool in both sandy barrier and back-barrier estuarine shorelines.

[1] Brodie, Katherine L., Tristan Dyer, Nicholas Spore, Richard Slocum, Annika O'Dea, Tucker Whitesides, and Renaud Alexander. In preparation. *Continuously Operating Dune-Mounted Lidar System at the Field Research Facility, A Report Detailing Lidar Collection, Processing, Evaluation, and Product Development*. ERDC/CHL Technical Report. Vicksburg, MS: U.S. Army Research and Development Center.

Figure 3-3. Map of proposed flight lines and areas of interest at FRF field site (UTM-18N).



Diverse vegetation exists on the FRF property. Although not recently classified, previous efforts provide an estimate of ecological diversity. A total of 178 species and 58 families of flora were collected and classified into 11 statistically distinct plant communities (i.e., foredune, wetland, oceanside shrub, sound-side shrub, and sound-side disturbed [Levy 1976]). As a result of the UAS experiment and work of EL participants, a 2017 vegetative survey can be produced. Coastline vegetation assessment for FRM is important for estimating dune stability (Ehrenfeld 1990).

In addition to natural features, the FRF houses several buildings and other man-made structures such as the pier. Such static, relatively simple structures, are advantageous for SfM analysis, ground control, and evaluating UAS capabilities for observing coastal structures and FRM in more developed environments.

With these interests in mind, organizers proposed flight lines and designated areas of interest for participants (Figure 3-3). Attendees were not required to fly these exact lines; however, ground control and target placement focused on these areas.

3.3 Target placement

Visual targets placed throughout the FRF compound served as ground control for photogrammetric analysis or UAS sensor evaluation. Painted 4 × 4 feet (ft) sheets made of Type 1 rigid polyvinyl chloride served as checkerboard ground control points (GCPs) for areas of variable topography (Figure 3-4). Cement cinderblocks anchored a corner of these targets. Beach flight lines had additional temporary GCPs deployed on the foreshore. Fixed FRF infrastructure, such as the flat portions of the roof and pier, had permanent 7 × 7 ft painted checkerboard GCPs.

GCP placement coincided with flight lines and provided ample coverage of the entire property. Figure 3-3 highlights planned target locations with respect to flight lines. A subset of targets served as *solution targets* (red vs. orange squares, Figure 3-5). Participants were to use only this subset when geo-referencing UAS data. Standardizing ground control eliminates variability based on GCP selection and allows for a more direct comparison of platform, sensor, and software performance. This target limitation did not apply to flights of limited field of view (i.e., beach hover flights). The remaining surveyed GCPs are necessary to evaluate the accuracy of UAS.

Figure 3-4. Images of GCPs for (A) variable , (B) fixed, and (C) beach topography. Red circles indicate GPS survey point. (D) Example aerial photography of all three types of targets shot by CHL X8+ platform.

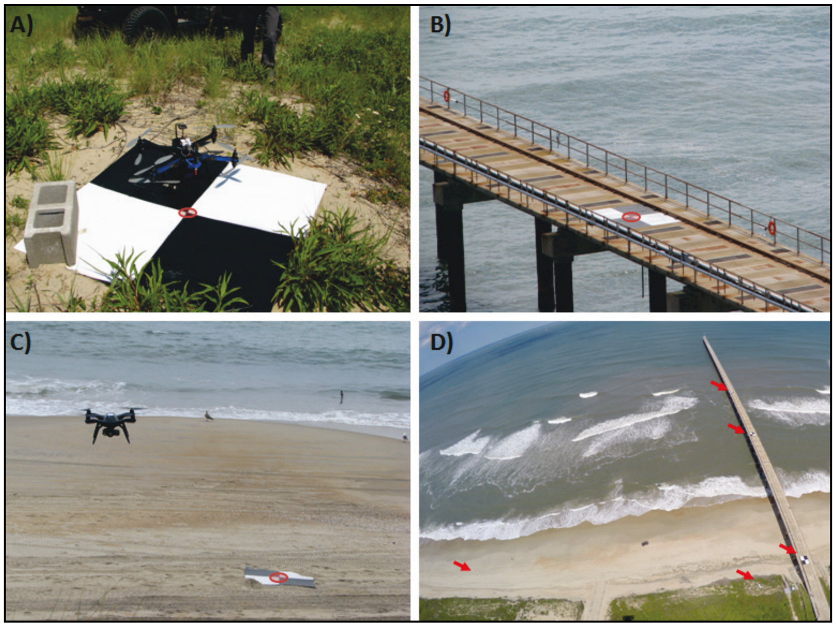
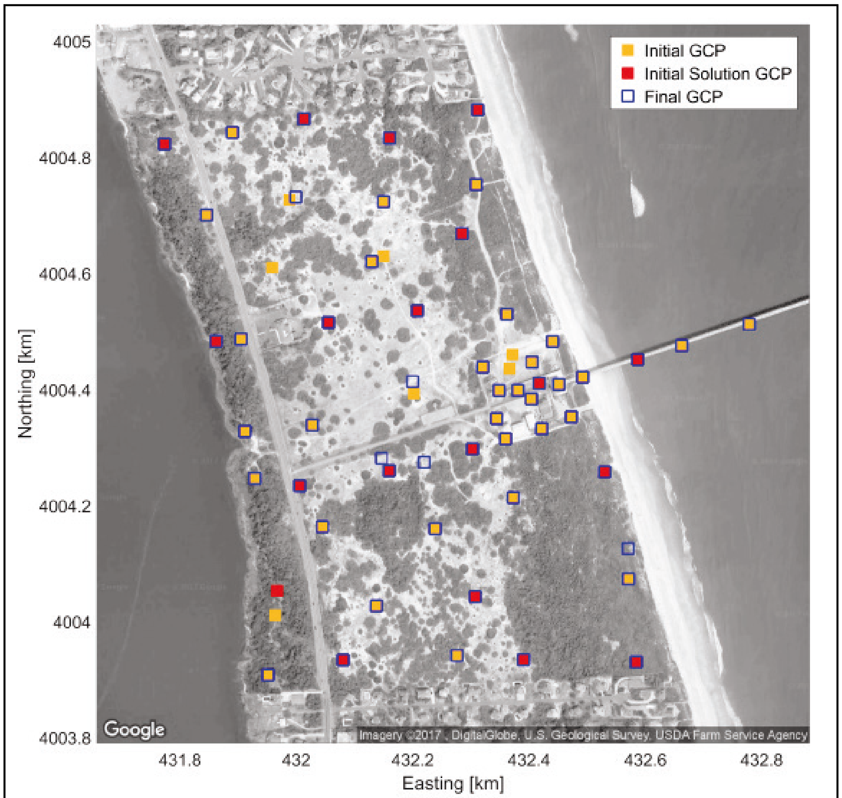
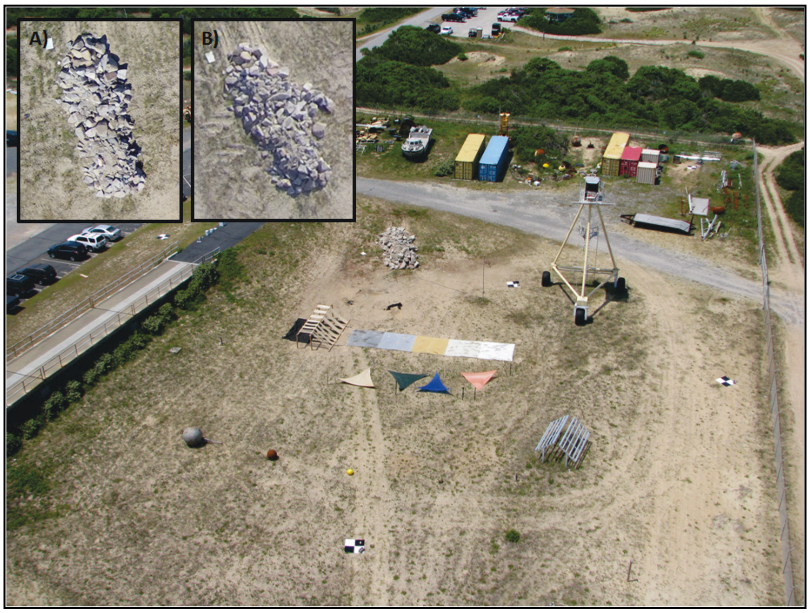


Figure 3-5. Map of ground control target placement surveyed before (June 2) and after (July 6) the experiment (UTM-18S). Solid boxes represent GCP surveys before the experiment; red indicates a solution target. Blue box outlines represent GCP surveys after the experiment.



The *Target Pad* area identified in Figure 3-3 encompassed all of the targets used for UAS sensor evaluation. Borrowed targets from the Corbin Remote Sensing Calibration Range, operated by the National Geodetic Survey and NGA, consisted of various sizes, shapes, colors, and hyper-spectral signatures (Figure 3-6). The CHL-FRF personnel also produced additional spherical objects and painted targets.

Figure 3-6. Image of target pad area and UAS evaluation targets. Camera position is east of the target pad, oriented west. Inset: Image of (A) intact and (B) destroyed mock jetty.



The CHL-FRF personnel also constructed a mock jetty, 3 m × 10 m, made from Class 2 rip-rap. The purpose of the jetty was to evaluate the capability of UAS to resolve key features of and damage to typical coastal structures. Each week the CHL-FRF operations team knocked down and rebuilt the jetty. Future analysis will compare before and after UAS imagery to determine the degree of change UAS can resolve (Figure 3-6 (A), (B)). Terrestrial lidar scans of the jetty and all the evaluation targets in the *Infrastructure Area* provide point clouds for control.

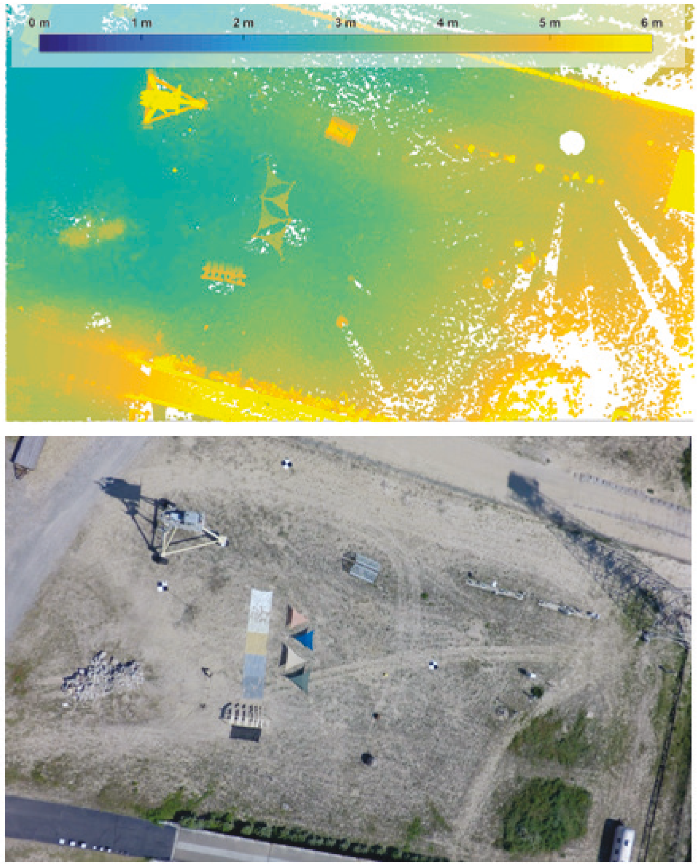
3.4 Control surveys

Extensive surveying of targets provided data for geo-rectification and quality assessment of UAS data. To georeference GCPs, a tripod-mounted RTK-GPS surveyed the center intersection of each GCP checkerboard for at least 180 epochs before the start of the experiment (Figure 3-4). RTK-GPS survey accuracy was +/- 0.025 m in the horizontal and vertical directions. Temporary beach target surveys, not shown, occurred immediately after a given flight.

In the third week of the experiment, after a wind event, a GCP appeared to have moved several meters. To address potential GCP movement, surveying occurred again after the experiment. Figure 3-5 maps GCP coordinates surveyed before (solid squares) and after (blue outlined squares) the experiment. GCP recovery rate was 54/57.

A stationary terrestrial lidar scanner provided point clouds of the Infrastructure Focus Area. The tripod-mounted Riegl VZ-1000 provided point clouds of areas from multiple stationary scans at various vantage points. Figure 3-7 displays an example point cloud of the infrastructure area.

Figure 3-7. Example point cloud in plan view (top) and near nadir UAS image (bottom) of target pad area. Point cloud scans performed 26 June 2017. NAVD88[1] elevation plotted in point cloud; color is saturated with a maximum of 6 m to highlight low-elevation targets. Imagery from CHL X8+.



Fixed reflector targets allowed for the geo-referencing of the scans. A plane-matching algorithm (LeWinter 2014) co-registers additional scans to the baseline scan performed during ideal conditions (26 June 2017 scan). Figure 3-8 identifies scan positions and reflector coordinates, surveyed in the same manner as the GCPs and in close temporal proximity to the baseline scan. Table 3-2 provides additional scan and point cloud information.

[1] North American Vertical Datum of 1988

Figure 3-8. Map of lidar scan positions and reflector targets (UTM-18S).
Inset: Image of reflector target.

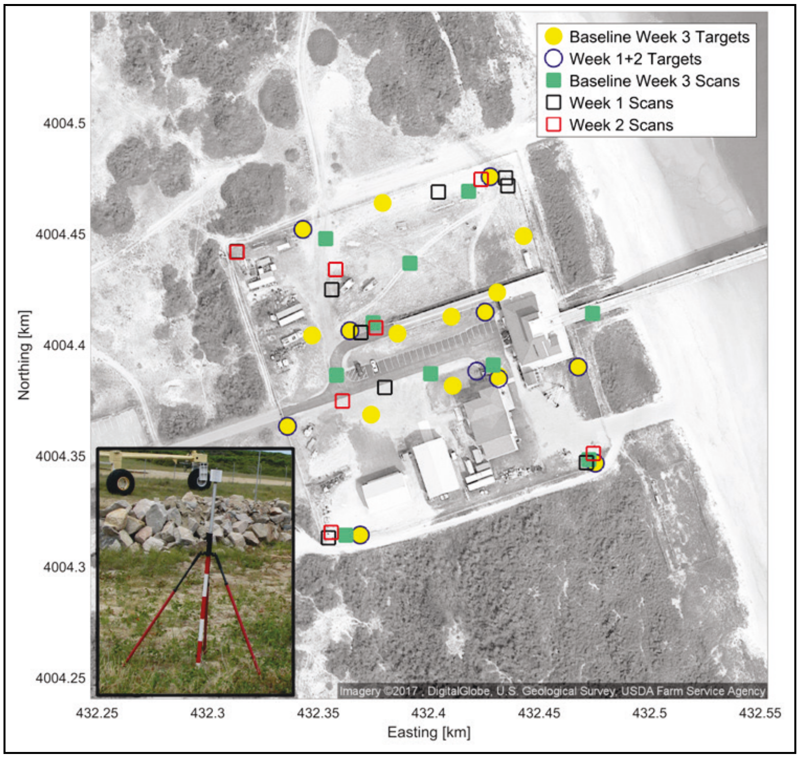
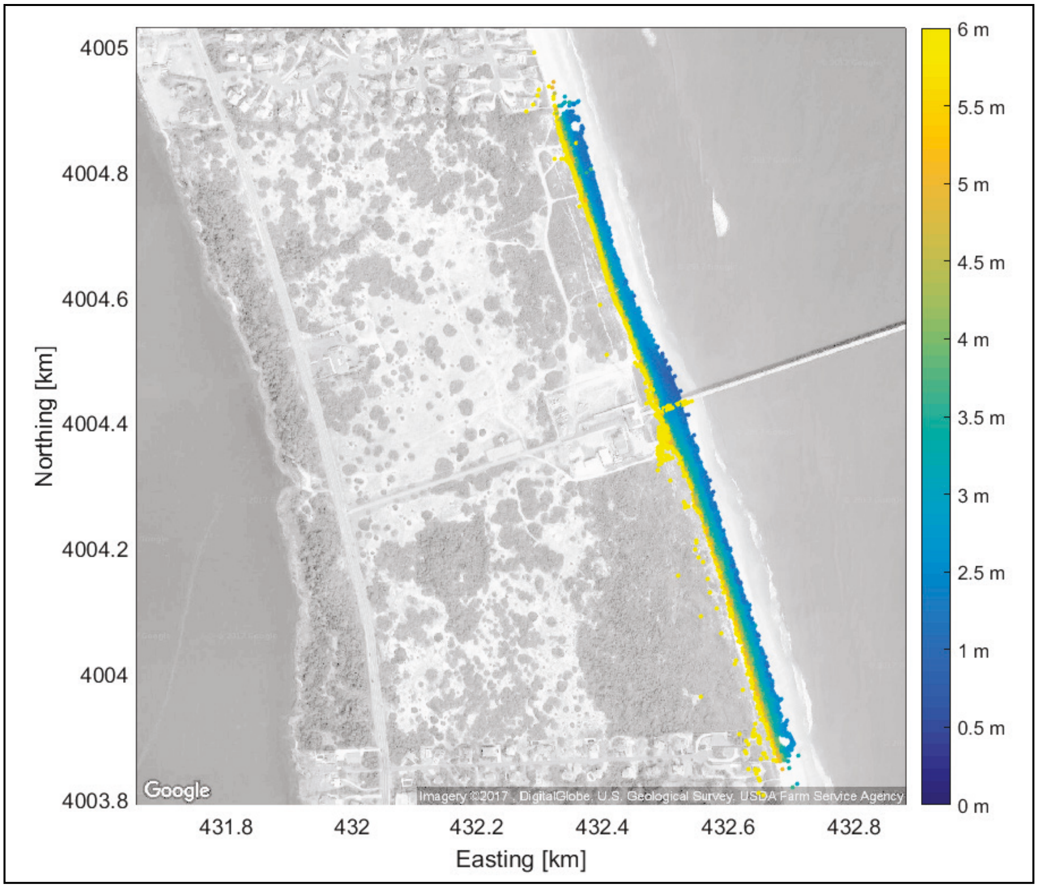


Table 3-2. List of stationary lidar control surveys. (IA refers to Infrastructure Area).

Scan	Date	No. of Scans	Horizontal (Φ) and Vertical (Θ) Scan Angular Resolution
IA with Jetty Intact	06/05/2017	9	Φ=0.04° Θ=0.04°
Jetty Destroyed	06/07/2017	2	Φ=0.04° Θ=0.04°
IA with Jetty Intact	06/12/2017	7	Φ=0.04° Θ=0.04°
Jetty Destroyed	06/14/2017	2	Φ=0.04° Θ=0.04°
IA with Jetty Intact	06/20/2017	5	Φ=0.04° Θ=0.04°
Complete Baseline IA with Jetty Destroyed	06/26/2017	10	Φ=0.04° Θ=0.04°

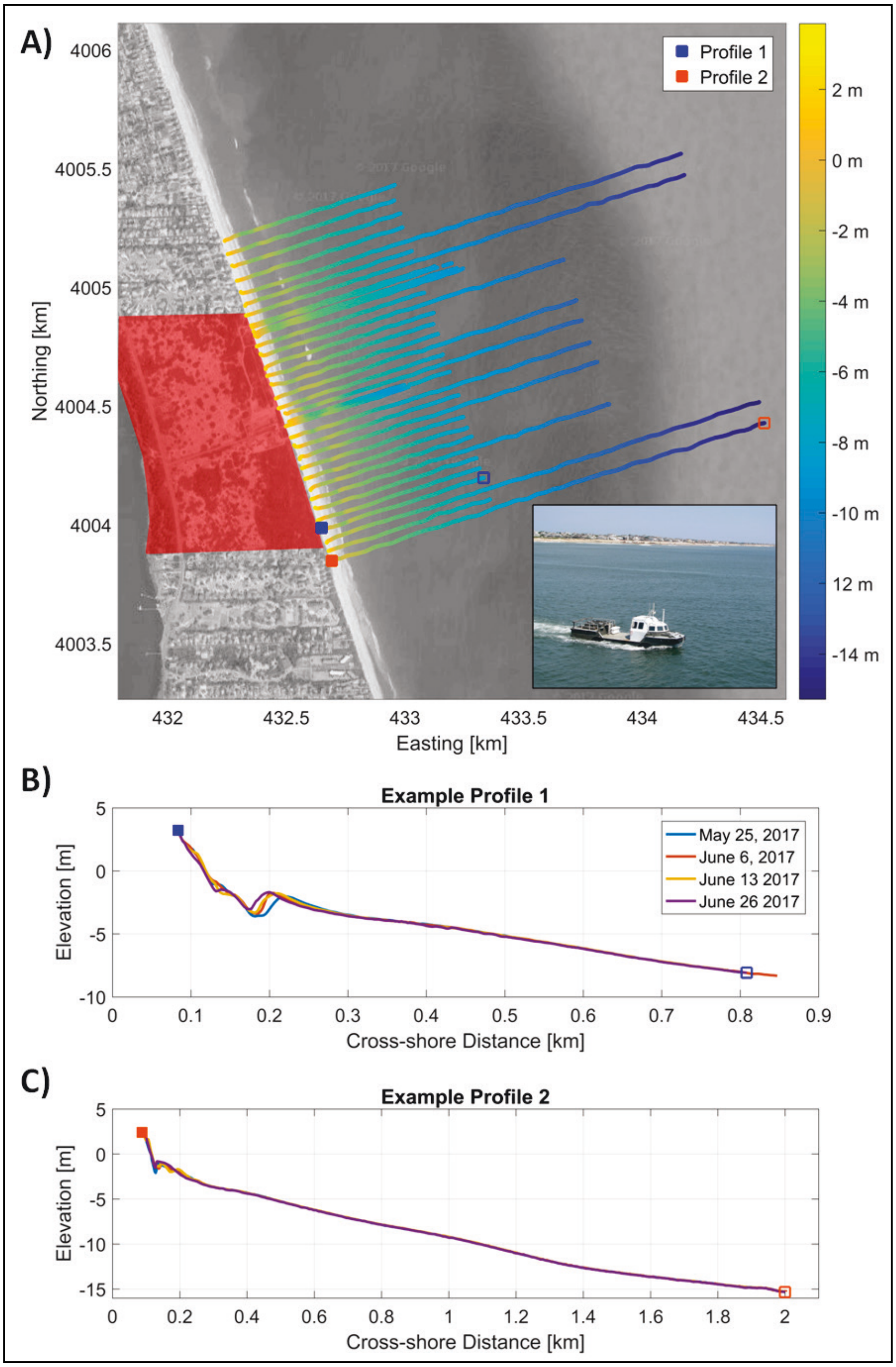
In addition to stationary lidar scans, the CHL-FRF utilized its Coastal Lidar and Radar Imaging System (CLARIS) to perform mobile terrestrial lidar scans when time was too limited for multiple stationary scans. The system and data analysis, detailed by Brodie and Spore (2017), provides 3D point clouds and DEMs over long distances ($O(10)$) kilometers (km) in relatively short time (few hours) with no ground control. The total error of the system is estimated to be 0.129 m; however, this may vary throughout the scan. The system, attached to a truck, scanned accessible areas of the interior FRF property as well as the dry beach along the beach flight line. Figure 3-9 shows an example CLARIS scan from June 15, 2017.

Figure 3-9. Example Claris point cloud collected on 15 June 2017. Elevations in NAVD88 and elevation color is saturated to highlight variation in low elevation topography.



Bathymetric surveys on the ocean coastline occurred once a week utilizing the Lighter Amphibious Resupply Cargo (LARC) amphibious vehicle. The LARC measures bathymetry up to 2 to 3 centimeters accuracy using an acoustic sonar and RTK-GPS (Forte et al. 2017). Typically, the LARC conducts extensive surveys monthly adding to the rich FRF bathymetric data archive starting from 1980. Figure 3-10 maps LARC transects throughout the experiment and derived bathymetry. Future analysis will compare LARC bathymetry with bathymetry derived from UAS.

Figure 3-10. (A) Map of LARC transects and measured bathymetry (NAVD88); data collected 25 May 2017. Red area indicates FRF property. (B)-(C) Example cross-shore profiles from measurements spanning 25 May–26 June 2017. Inset: LARC surveying on 13 June 2017.



3.5 Meteorological conditions

Field site meteorological conditions are an important consideration for UAS activity. Small aircraft such as UAS are very susceptible to high wind speeds, and manufacturers recommend maximum wind speed conditions for flying. Even if below the maximum threshold, strong gusts can induce strafing, wobbling, and crabbing behavior in flight and reduce data quality. Rain is also a limiting flying factor due to exposed sensors and UAS components.

Sensors also have meteorological limitations as well. RGB photography requires sufficient daylight and visibility (limited by fog). Lidar requires minimal aerial particulates such as rain, fog, or high humidity. Hyper-spectral measurements require consistent ambient daylight, either completely cloudy or clear skies preferred in mid-day. IR measurements fail to differentiate heat signatures when environments are saturated (i.e., mid-day with extreme sunlight.)

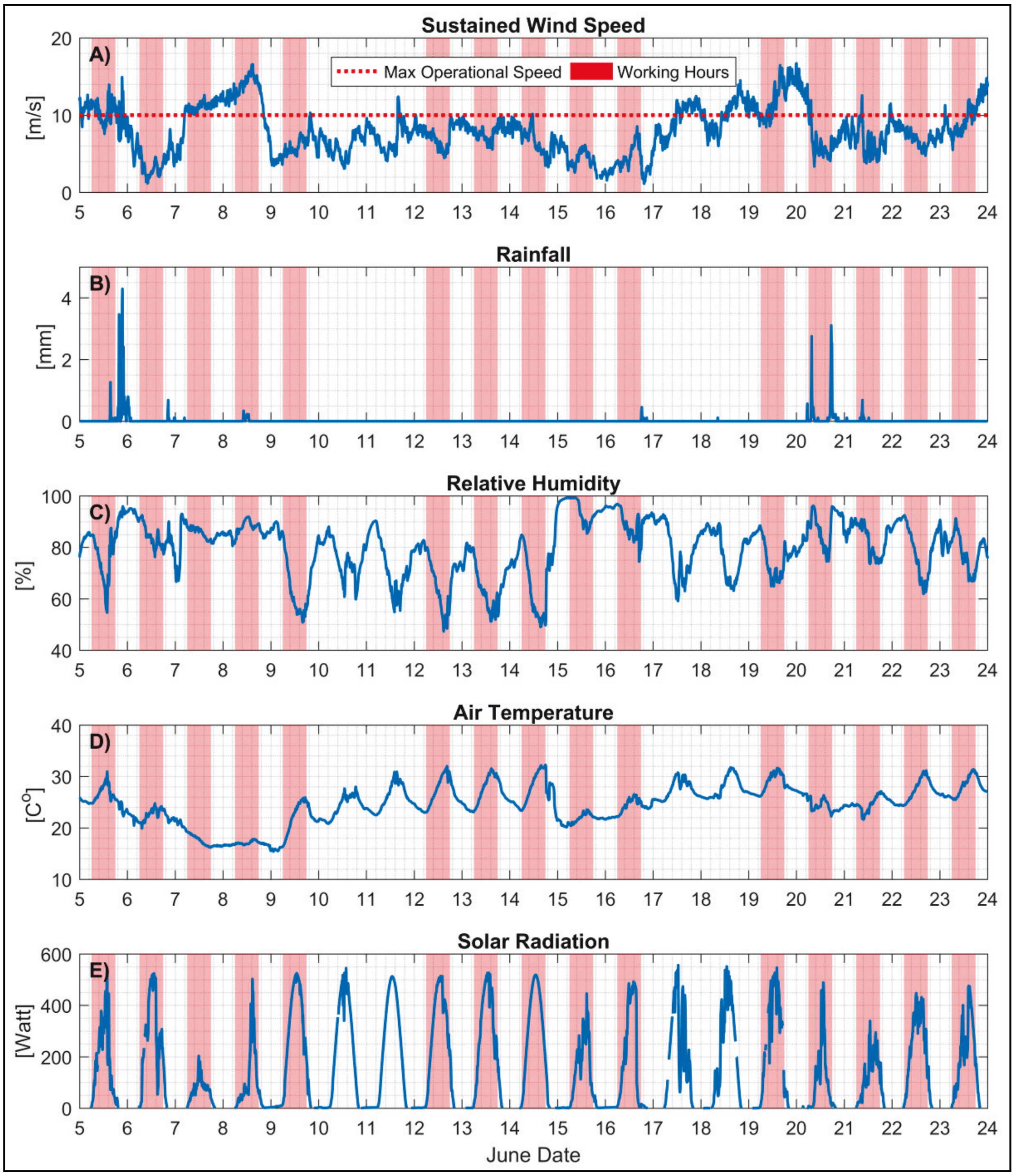
The FRF has a suite of meteorological sensors at the end of the pier and in the inner compound. Wind speed, rain fall, humidity, solar radiation, air temperature, and pressure measurements are available for quality control and calibration of UAS sensor data.

Figure 3-11 shows daily meteorological data over the experiment duration, highlighting conditions during operational hours (06:00–18:00 local time). High sustained wind speeds (Figure 3-11 (A)) significantly limited flight operations for 5 out of 15 days (June 5, 7, 8, 19, 23). Rainfall (Figure 3-11 (B)) only affected flights for one day (June 20). Fog, which typically occurs when relative humidity reaches 100% (Figure 3-11 (C)), grounded flights on the morning of June 15.

Air temperature (Figure 3-11 (D)) and solar radiation (Figure 3-11 (C)) did not limit flight operations during the experiment but did limit sensor performance. Days and afternoons with high temperatures limited IR data capture; typically, IR use occurred in the morning. Rain and winds accompanied days with lower afternoon temperatures. Few days were optimum for hyper-spectral instruments (June 9, 14); the only solar variation was due to the sun's long period movement in the sky. Other days, with a jagged appearance, had high frequency variations due to clouds.

Figure 3-11 shows meteorological conditions were a limiting factor for UAS activity and data collection. However, it is also important to consider that optimum days for UAS operations (clear skies with little wind) are also optimum for other aviation traffic, which can also affect UAS data collection efforts.

Figure 3-11. Meteorological data collected at FRF during the experiment. Working hours refers to FRF operational hours (06:00–18:00) when flying occurred. Maximum operational speed refers to a generalized maximum wind speed (e.g., 10 meters per second [m/s]) safe to operate UAS.



3.6 Aviation awareness

The FRF field site is in line with a low-altitude air traffic corridor (<300 m) that runs along the Outer Banks. Traffic is particularly busy during the summer months due to banner planes focused on beachgoers and passing coast guard helicopters. This is in addition to recreational and military aviation activity from the nearby Coast Guard and Naval stations in Elizabeth City, NC, and Norfolk/Virginia Beach, VA, respectively.

To prepare the field site for UAS activity, organizers filed a Federal Notice to Airmen (NOTAM) with the FAA. NOTAMs are advisories to pilots of potential hazards along a flight path. The NOTAM, identified as # 05/018, specifies UAS activity up to an elevation of 1200 ft and in a 1 km radius around the FRF property for 2 years after 20 April 2017.

Dissemination of NOTAMs is through either telecommunication, online in the Federal NOTAM System, or published in the Notices to Airmen Publication, which is issued every 28 days by the FAA. To facilitate dissemination, FRF organizers also directly informed local airport managers and posted flyers at nearby runways and airports (First Flight Airport in Kill Devil Hills, NC, and Dare County Regional Airport in Manteo, NC).

To supplement the NOTAM, the FRF purchased an FAA radio to immediately telecommunicate with pilots flying near or over the facility. The radio, a Yaesu FTA-550, communicated on the frequency 122.9 megahertz (MHz), and listened over frequencies 122.7–123.05 MHz. These are standard Universal Communications frequencies provided by the Federal Communications Commission for use by aviation pilots not near a control tower. Particularly, the First Flight and Dare Country Regional airports communicate over 122.9 and 122.8 MHz, respectively. During flight operations and data collection, the FAA radio proved to be an indispensable tool since the NOTAM was frequently disregarded.

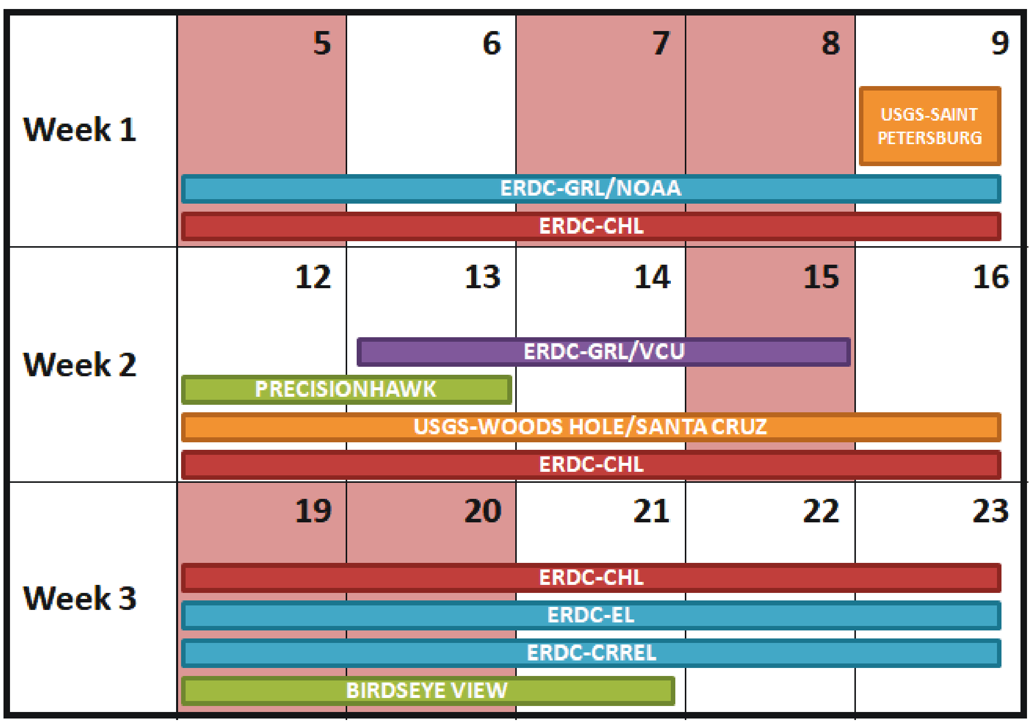
4 Data Collection

Data collection commenced on 5 June 2017 and officially ended 23 June 2017; however, additional CHL-FRF UAS and ground control data collection continued for several weeks after. This chapter provides the experiment schedule as well as describes flight operation protocol for data collection. The chapter also provides example flight lines from actual flight data as well as statistics and tables describing all of the flights.

4.1 Flight operations

Participants arrived at scheduled times spread over the 3-week period to reduce airspace congestion and mitigate strain on CHL-FRF personnel and resources (Figure 4-1). Figure 4-1 also highlights days with poor meteorological conditions, and available flight time was limited or non-existent.

Figure 4-1. Participant schedule for UAS for FRM experiment. Red-shaded days represent poor weather conditions with limited flying.



For days with adequate weather, daily flight operation protocol began with a morning meeting of all participants and CHL-FRF personnel directly involved in the experiment. Topics discussed included weather and anticipated flight plans of each participant group to avoid airspace conflict.

CHL-FRF personnel provided handheld radios to each group for communication throughout the day. After the meeting, each group retreated to its staging area to prepare for data collection.

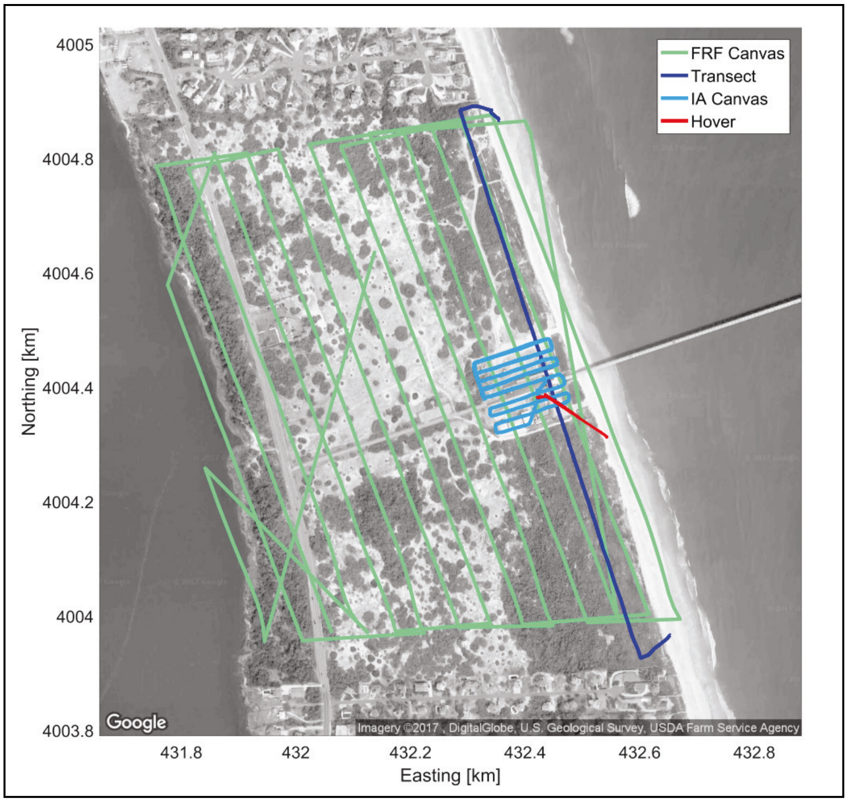
CHL-FRF personnel escorted groups during takeoff, data collection, and landing of every flight. Before takeoff, CHL-FRF personnel radio notified all groups of takeoff location and anticipated flight path and elevation. An FRF employee, either positioned with a group or at a high vantage point, announced UAS activity and the NOTAM over the FAA radio. If there were no objections from other groups or CHL-FRF employees, takeoff occurred. While in-flight, the CHL-FRF employee with the FAA radio observed the skies and communicated UAS activity with incoming aircraft and aircraft activity with experiment participants. If it appeared incoming aircraft were too close to UAS and could not divert, UAS were instructed to immediately land. Before landing, groups informed CHL-FRF personnel, and it was communicated over the radios as in takeoff. With this protocol, multiple flights could occur simultaneously as long as elevations or flight paths did not cross.

4.2 Example flight lines

All flights during the experiment sorted into one of three different categories: hover, canvas, and transect (Figure 4-2). Hover flights, which are only available to multi-rotor aircraft (with the exception of the BirdsEye FireFly), described aircraft traveling to a specific elevation and remaining stationary for an extended time. Flights could be flown manually or programmed as a loiter waypoint in the UAS autopilot. Flights aimed at producing wave-related time series for bathymetry or surf-zone hydrodynamic observations typically utilized hover flights (except the FRF X-8 discussed in Chapter 2). Such flights were not useful for photogrammetric mapping data that required SfM analysis due to the lack of motion.

Canvas flights, which featured multiple transects across a given area, are appropriate for photogrammetric, hyperspectral, or lidar mapping. Fixed-wing aircraft and multirotor platforms can fly canvas flights; however, fixed-wing aircraft can typically fly longer due to design. Multirotor platforms limited by battery flew transect flights (i.e., single flight lines that could also generate photogrammetric mapping products). Canvas and transect flights are typically programmed into an autopilot, particularly for fixed-wing aircraft. Frequency of each type of flight is described along with other statistics in Section 4.3.

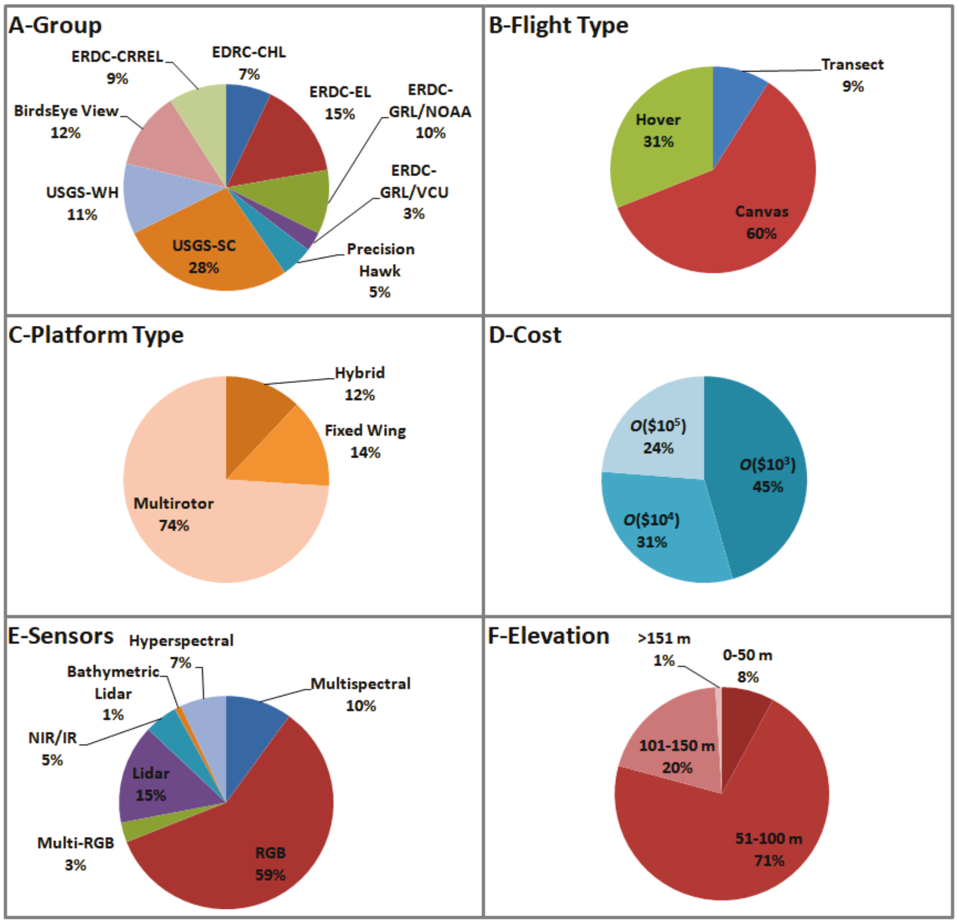
Figure 4-2. Example trajectories from flight data. FRF canvas is from Birdseye View FireFlyPro6. IA canvas and transect are from CHL x8+. Hover is from USGS-SC 3DRSolo.



4.3 Flight summary statistics

By the end of the experiment, there were 180 flights totaling flight time over 46 hours. A full list of all the flights is in Appendix A. Figure 4-3 summarizes the relative occurrence of different flight parameters, such as flight type, elevation, and sensor payload. Total flight time percentage defines relative occurrence. Using this metric, fixed-wing aircraft and associated parameters may be over-represented due to their increased battery life and flight time. In addition, metrics depend on the duration of group participation. USGS-SC participated for the whole second week with relatively good weather and focused largely on repetitive hover flights. As a result, its platform, the 3DRSolo, will show high representation. The analysis does not include manned flights by USGS-SP and JALBTCX.

Figure 4-3. Flight summary statistics from UAS for FRM experiment. Percentages defined by share of total flight time.



With the exception of Precision Hawk and USGS-SC, all participant groups had similar flight time in the air (Figure 4-3 (A)). Precision Hawk was low due to only 1 day of flying. USGS-SC accounted for almost one-third of flights; the pilot had a rotation of beach hover flights that were repeated numerous times every day for an entire week with the intention to derive bathymetric estimates.

These USGS-SC flights manifest themselves in Figure 3-4 (B) as well; over 30% of the flights were hover-type flights. As shown in Appendix A, other groups only performed a few hover flights for wave shape analysis with lidar and RGB sensors. Transects had the smallest percentage, and most were CHL flights with a multi-camera, wide-field-of-view camera system. The multi-camera system required long dwell time for bathymetric estimates, thus the battery could only last for one slow-moving transect. Most group's flight time consisted of canvassing, comprised of both fixed wing and multirotor platforms, which had enough battery for multiple transects across the property and did not require long dwell time (focus was on topographic estimates).

Multirotor platforms spent the most time in the air during the experiment (Figure 3-4 (C)). The only hybrid platform was the BirdsEye View FireFLY6 Pro; however, it only utilized its multirotor features for vertical takeoffs and landings during this experiment. For data collection, it could therefore be considered a fixed wing. Thus, multirotor platforms accounted for more than twice the total flight time of fixed wings. This is a result of more research groups having multirotor platforms and an increased number of flights due to the limited spatial coverage of some of the low-cost multirotor platforms.

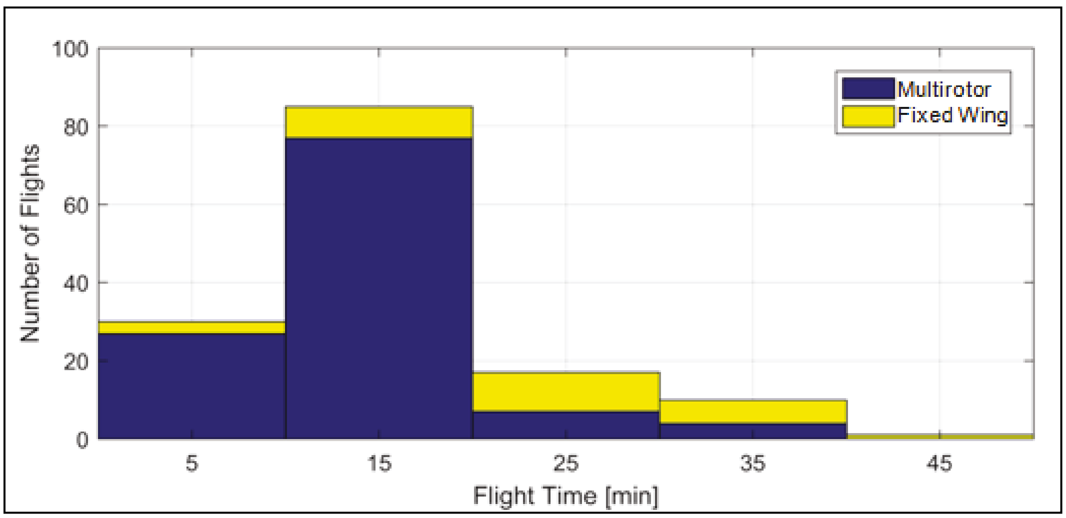
Low-cost platforms, on the order of $1,000, accounted for almost half of the flight time (Figure 4-3 (D)). Due to low cost, more participants could afford these UAS. In addition, with less cost there is typically more simplicity and less financial liability; pre-flight procedures were shorter, and these flights occurred more often. The mid-range platforms were all fixed wing and hybrid platforms with the exception of the CHL X8+. Although the X8+ is a low-cost platform ($1,000), the added IMU significantly increased the cost (+$15,000). The most expensive platforms, the RiCOPTER and SkyCrane, were large multirotor platforms with extended battery life and thus relatively long flight times. The increased cost (>$200,000) is a result of the increased battery life, size, and advanced sensors onboard. Future analysis will compare platform cost against the relative quality of results.

RGB imagery was by far the most utilized sensor, accounting for over half of the total flight time (Figure 4-3 (E)). Photogrammetric software packages aside, RGB prevalence is due to the relatively cheap cost of RGB cameras. Lidar was the second most utilized; the bathymetric lidar is in development and only tested on one RiCOPTER flight. Multiple groups used sensors to measure spectra outside of the visible band (IR thermal imaging and multispectral), however, not as often as their RGB or lidar systems. This highlights the increased desire for terrain and infrastructure mapping relative to plant classification from the participants.

Most flights flew at an elevation between 51 and 100 m (Figure 4-3 (F)). For many sensors and platforms, these elevations provided adequate field of views, balancing needed resolution, battery life, and avoidance of ground structures. To test field of view, one multirotor flight flew a short time (<5 min) at 350 m. Low-altitude flights (<50 m) were for hovering wave shape analysis over the water. Fixed-wing platforms typically flew at higher altitudes to take advantage of higher wind speeds for increased lift (100–150 m).

Figure 4-4 highlights the discrepancies in flight duration between multirotor platform and fixed-wing platforms. Most flights during the experiment were between 10 and 20 min in duration. Most of these flights were multirotor platform flights. Most fixed-wing flights were between 20 to 30 min long. Shorter fixed-wing flights were typically to finish incomplete canvases. Longer multirotor platform flights were the more expensive and larger platforms. Overall, there were fewer fixed wing flights because (1) fewer participants used them and (2) their longer battery life increased flight time, which required fewer actual flights to achieve the same spatial coverage as some multirotor platforms.

Figure 4-4. Histogram of individual flight durations. Bins are centered on tick marks and 10 min wide. Birdseye View is considered a fixed-wing platform in this analysis.



5 Data Aggregation and Dissemination

To participate in the experiment, attendees agreed to provide organizers flight logs as well as all collected raw and processed data. In return, organizers granted participants access to collected UAS and ground control data from all attendees, stored on an in-house CHL Thematic Real-time Environmental Distributed Data Services (THREDDS) data server. This chapter will discuss the following: how the collected data is stored and organized, as well as its dissemination on the THREDDS data server.

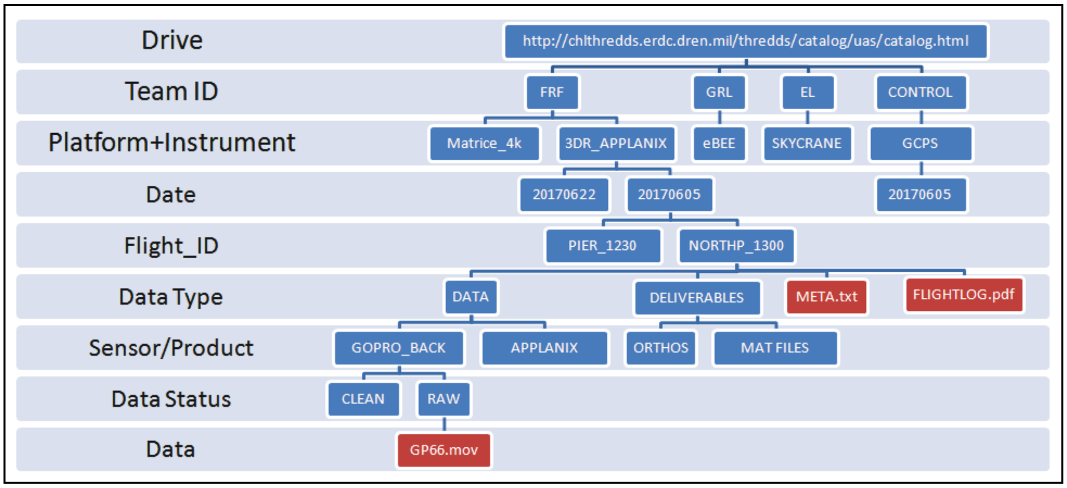
5.1 Data aggregation and organization

Due to varying workflows and processing requirements of participants, data upload occurred in a piece-meal fashion. Some participants provided raw and processed data immediately after collection (< 5 days); others provided only raw data immediately and processed data at a later date (> weeks); and some provided raw and processed data together later, as well. Due to the large nature of the individual files (≈0.5 gigybyte), physically mailing hard drives to the FRF was the most convenient method for data transfer.

Organizers provided participants with a template directory structure for data organization (Figure 5-1). The template served only as a guide; some platforms with integrated payloads did not allow for the separation of raw data by sensor or flight. If sensors or flights could not be differentiated, organizers asked for descriptive directory names or metadata text files. The prerequisite directory hierarchy facilitated organization as data from differing groups, sensors, and refinement intermittently arrived.

Once at the FRF, the data are stored on four 4 terabyte (TB) SATA hard-drives arranged in a redundant array of independent disks (RAID) 5 configuration, allowing for 10.47 terabytes of total storage. From the FRF R&D network, organizers are able to secure shell into the CHL servers in Vicksburg, MS, to upload data to the publically accessible CHL THREDDs data server.

Figure 5-1. Template data organization for UAS participants. Blue boxes represent directories, and red boxes represent files.



5.2 Data dissemination

UAS data dissemination occurred through the CHL THREDDS Data Server (TDS). TDS is a web server designed for scientific datasets using a variety of remote data access protocols (Domenico et al 2006). Although TDS has many additional features, for this experimental dataset it only provides bulk file access to public users through hypertext transfer protocol secure.

Participants can access the data at http://chlthredds.erdc.dren.mil/thredds/catalog/uas/catalog through a web-browser graphical user interface, Unix or Windows shell application such as wget, or the webread command in MATLAB (a numerical computing environment). Unfortunately, the UAS files on the TDS cannot be downloaded in batches. Individually initiating each file download is tedious when downloading thousands of images for one flight; thus, a MATLAB script was developed by Tyler Hesser (ERDC-CHL) to batch-download files. The code is recursive and preserves the directory structure that is key to the dataset's organization. The MATLAB code named "crawl_uas_thredds.m" is found on the TDS.

6 Summary

The chief goal of the June 2017 Duck UAS Pilot Experiment was to evaluate existing and new UAS-based survey and monitoring techniques beneficial to USACE FRM. The coordinated data collection has provided comprehensive coverage of the ERDC-CHL), FRF environment. These datasets provide the foundation for quantitatively comparing the pros and cons of different platforms, sensor packages, and processing techniques against each other as well as traditional survey methods.

Nine UAS flight teams conducted 180 UAS flights with 10 different basic types of air frames (6 multi-rotor and 4 fixed-wing platforms) as well as two traditional fixed-wing plane overhead surveys between June 5 and June 24. The UAS flights combined for over 2,782 min of air time across estuarine, dune, beach, and nearshore environments, including different types of structures and man-made infrastructure. The diverse array of sensors that included lidar, multispectral packages, and high-resolution cameras. These data can be used to assess topography, bathymetry, surf-zone hydrodynamics, terrain, land cover, vegetation, and structures.

The knowledge generated from these resources will support the development of defendable and consistent UAS-based methodology and data products designed to seamlessly integrate with numerical models to monitor and assess coastal and riverine environments, associated infrastructure, and ecosystem health. Through these advances, USACE will be better able to understand UAS approaches to manage flood risks by reducing risks, increasing resilience, and advancing sustainable infrastructure on a system-wide scale.

6.1 Logistical highlights and future improvements

As detailed in this report, the UAS for FRM Duck Pilot Experiment proved to be an overall success with accomplishment of its goals. The CHL-FRF property proved to be a quality testing ground for UAS platforms. Future multi-party UAS experiment planning should keep the following factors in mind.

6.1.1 Experiment setup

The CHL-FRF team worked with partners to develop a suitable target pad and mock infrastructure prior to the experiments. Experiment setup and followup required a full week of staff time on either side of UAS flight windows to ensure adequate target deployment, surveying, and other calibration activities. GCPs should be designed with heavy anchor points or attachments to prevent shifting from higher-than-anticipated wind (for example, GCPs anchored with ~13 kg cinder blocks shifted in a 15 m/s wind event). Though June in Duck, NC, does have a number of climatic benefits to it (comfortable working weather, low winds, small waves), non-summer season months may be more practical to avoid beach tourists and low-flying banner advertising planes.

6.1.2 Experiment operations

The number of UAS flight teams participating (nine) appeared to be the near-ideal number for an experiment of this length and size. Given the preference of multiple different platforms to operate at certain altitudes and areas, supporting more than three to four teams per week would have proven difficult. Morning meetings were effective tools for different teams to lay out their plans. Competition for airspace arose more frequently during instances of less upfront communication. The CHL-FRF radios also were a practical solution to avoiding airspace conflicts by coordinating takeoffs, landings, and flights. Paper logs (flight teams own or FRF-provided versions) were a good tool to ensure that adequate log information was summarized.

The FAA radio was critical to safe flight operations. Multiple low-flying banner advertising planes, sightseeing and recreational planes, military and coast guard aircraft, and medical evacuation helicopters frequently entered the airspace above the FRF property, despite the NOTAM in place. The FAA radio allowed for proper communications to alert pilots and deal with any mid-air approaches between their aircraft and UAS platforms.

As may be expected, several different teams did experience occasional technical difficulties with particular platforms, which led to delays or changes in flight arrangements. These difficulties emphasized the benefits of having some redundancy in available platforms to best collect data in a more continuous manner.

6.1.3 Experiment participation and extension

The 11 participating flight teams provided a good variety of airframes, including multi-rotor, fixed-wing, and manned airborne platforms. Though there was good ERDC laboratory representation and samples from federal agencies and private industry, academic participation was somewhat limited. Formal invitations could have been extended earlier to reach more UAS research operators; however, any greater number of participants may have complicated comprehensive data collection by different teams. Regrettably, some colleagues may have felt left out of initial conversations and planning; however, many expressed willingness to participate in future endeavors.

Participating teams were invited to weekly calls preceding the experiment to facilitate planning and invite buy-in to target placement and experiment setup. Though communicated and provided over email, clarity over the availability and details of specific experiment resources can never be emphasized enough to fully prepare external participants.

VIPs learned about the overall experiment and work unit before seeing live demos of several ERDC laboratory UAS flights in the afternoon of June 22. The population of VIP visitors was mainly made up of ERDC employees. Despite attempts to recruit USACE leaders from Headquarters, most were unable to attend. Extension of such demonstrations to USACE district personnel also could prove beneficial at similar events in the future. As the project proceeds into FY18, UAS for FRM district pilot projects may prove opportunities for project education and outreach as well.

6.2 Next steps

Participating teams have currently been processing their data and data products to share with CHL-FRF staff and other participants. Submitted data have been stored on the CHL THREDDS server for participating teams. Final results from the experiment will be reported as the analysis is completed and the results are refined.

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Appendix A: Flight Logs

BirdsEyeView						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/19/2017	10:55	34	FireFly6 PRO	RGB	Canvas	120
6/19/2017	12:07	33	FireFly6 PRO	RGB	Canvas	120
6/19/2017	13:29	44	FireFly6 PRO	RGB	Canvas	120
6/19/2017	14:26	30	FireFly6 PRO	RGB	Canvas	120
6/20/2017	13:21	29	FireFly6 PRO	RGB	Canvas	120
6/20/2017	14:12	40	FireFly6 PRO	RGB	Canvas	120
6/20/2017	15:21	27	FireFly6 PRO	RGB	Canvas	120
6/21/2017	13:45	37	FireFly6 PRO	RGB	Canvas	120
6/21/2017	14:47	40	FireFly6 PRO	RGB	Canvas	120
6/21/2017	15:42	27	FireFly6 PRO	RGB	Canvas	100

PRECISIONHAWK						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/12/2017	7:15	20	Lancaster	Lidar	Canvas	50
6/12/2017	7:55	20	Lancaster	Lidar	Canvas	50
6/12/2017	12:11	6	DJI Matrice	Multispectral	Transect	120
6/12/2017	9:46	22	DJI Matrice	Multispectral	Transect	120
6/12/2017	10:10	9	DJI Matrice	Multispectral	Transect	120
6/12/2017	10:39	25	DJI Matrice	RGB	Canvas	120
6/12/2017	11:07	5	DJI Matrice	RGB	Canvas	120
6/12/2017	11:22	22	DJI Matrice	RGB	Canvas	120
6/12/2017	11:48	8	DJI Matrice	RGB	Canvas	120
6/12/2017	12:03	5	DJI Matrice	RGB	Transect	120

JALBTCX						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/24/2017	13:05	123	Cessna 406	Lidar, Bathymetric Lidar, RGB Hyperspectral	Transect	400
USGS-SP						
6/9/2017	12:28	388	Cessna 182	RGB	Canvas	1,000
USGS-WH						
6/12/2017	12:46	15	3DRSolo	RGB	Canvas	100
6/12/2017	13:10	8	3DRSolo	RGB	Canvas	100
6/12/2017	14:00	13	3DRSolo	RGB	Canvas	80
6/12/2017	14:08	12	3DRSolo	RGB	Canvas	80
6/12/2017	14:32	7	3DRSolo	RGB	Canvas	80
6/12/2017	14:46	14	3DRSolo	RGB	Canvas	80
6/12/2017	17:23	13	3DRSolo	RGB	Hover	100
6/13/2017	10:42	13	3DRSolo	RGB	Canvas	100
6/13/2017	11:06	11	3DRSolo	RGB	Hover	100
6/13/2017	14:04	15	3DRSolo	RGB	Canvas	100
6/13/2017	14:22	15	3DRSolo	RGB	Canvas	100
6/13/2017	14:47	15	3DRSolo	RGB	Canvas	100
6/13/2017	15:26	15	3DRSolo	RGB	Canvas	100
6/13/2017	16:21	11	3DRSolo	Multispectral	Canvas	70
6/13/2017	16:36	14	3DRSolo	Multispectral	Canvas	70
6/13/2017	16:56	14	3DRSolo	Multispectral	Canvas	70
6/13/2017	17:16	13	3DRSolo	Multispectral	Canvas	70
6/13/2017	17:39	15	3DRSolo	Multispectral	Canvas	70
6/14/2017	10:23	7	3DRSolo	RGB	Transect	80
6/14/2017	14:47	14	3DRSolo	Multispectral	Canvas	70
6/14/2017	15:24	12	3DRSolo	Multispectral	Canvas	70
6/14/2017	16:02	15	3DRSolo	Multispectral	Canvas	70
6/14/2017	17:18	10	3DRSolo	RGB	Transect	70
6/14/2017	17:35	9	3DRSolo	RGB	Transect	70
6/15/2017	12:59	12	3DRSolo	RGB	Canvas	100
6/15/2017	12:31	7	3DRSolo	RGB	Hover	30

USGS-SC						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/12/2017	12:58	15	3DR Solo	RGB	Hover	100
6/12/2017	15:51	15	3DR Solo	RGB	Hover	100
6/12/2017	17:35	15	3DR Solo	RGB	Hover	100
6/13/2017	10:40	15	3DR Solo	RGB	Hover	100
6/13/2017	12:29	15	3DR Solo	RGB	Hover	100
6/13/2017	14:53	15	3DR Solo	RGB	Hover	100
6/13/2017	17:03	15	3DR Solo	RGB	Hover	100
6/14/2017	10:43	15	3DR Solo	RGB	Hover	100
6/14/2017	12:29	15	3DR Solo	RGB	Hover	100
6/14/2017	14:45	15	3DR Solo	RGB	Hover	100
6/14/2017	15:08	15	3DR Solo	RGB	Hover	100
6/15/2017	10:40	15	3DR Solo	RGB	Hover	100
6/15/2017	13:15	15	3DR Solo	RGB	Hover	100
6/15/2017	15:11	15	3DR Solo	RGB	Hover	100
6/16/2017	8:33	15	3DR Solo	RGB	Hover	100
6/16/2017	10:54	15	3DR Solo	RGB	Hover	100
6/12/2017	11:42	15	3DR Solo	RGB	Hover	100
6/12/2017	13:55	15	3DR Solo	RGB	Hover	100
6/12/2017	16:21	15	3DR Solo	RGB	Hover	100
6/13/2017	10:08	15	3DR Solo	RGB	Hover	100
6/13/2017	12:05	15	3DR Solo	RGB	Hover	100
6/13/2017	14:25	15	3DR Solo	RGB	Hover	100
6/13/2017	16:40	15	3DR Solo	RGB	Hover	100
6/14/2017	10:19	15	3DR Solo	RGB	Hover	100
6/14/2017	12:05	15	3DR Solo	RGB	Hover	100
6/14/2017	14:20	15	3DR Solo	RGB	Hover	100
6/14/2017	16:23	15	3DR Solo	RGB	Hover	100
6/15/2017	10:08	15	3DR Solo	RGB	Hover	100
6/15/2017	12:52	15	3DR Solo	RGB	Hover	100
6/15/2017	14:19	15	3DR Solo	RGB	Hover	100
6/16/2017	8:12	15	3DR Solo	RGB	Hover	100
6/16/2017	10:33	15	3DR Solo	RGB	Hover	100

USGS-SC (cont.)						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/12/2017	14:00	15	3DR Solo	RGB	Hover	100
6/12/2017	16:50	15	3DR Solo	RGB	Hover	100
6/13/2017	11:25	15	3DR Solo	RGB	Hover	100
6/13/2017	12:57	15	3DR Solo	RGB	Hover	100
6/13/2017	15:22	15	3DR Solo	RGB	Hover	100
6/13/2017	17:28	15	3DR Solo	RGB	Hover	100
6/14/2017	11:24	15	3DR Solo	RGB	Hover	100
6/14/2017	12:53	15	3DR Solo	RGB	Hover	100
6/14/2017	15:12	15	3DR Solo	RGB	Hover	100
6/14/2017	17:46	15	3DR Solo	RGB	Hover	100
6/15/2017	11:06	15	3DR Solo	RGB	Hover	100
6/15/2017	13:38	15	3DR Solo	RGB	Hover	100
6/15/2017	15:33	15	3DR Solo	RGB	Hover	100
6/16/2017	8:55	15	3DR Solo	RGB	Hover	100
6/16/2017	11:33	15	3DR Solo	RGB	Hover	100
6/15/2017	15:47	15	3DR Solo	RGB	Transect	80
6/15/2017	12:25	15	3Dr Solo	RGB	Hover	30
6/15/2017	16:40	15	3Dr Solo	RGB	Canvas	50
ERDC-CRREL						
6/21/2017	14:45	27	RiCOPTER	Lidar + RGB	Canvas	60
6/21/2017	17:18	35	RiCOPTER	Lidar + RGB	Canvas	60
6/22/2017	10:32	28	RiCOPTER	Lidar + RGB	Canvas	60
6/22/2017	14:21	23	RiCOPTER	Lidar + RGB	Transect	30
6/22/2017	17:27	33	RiCOPTER	RGB+Bathymetric Lidar	Canvas	20
6/23/2017	10:01	36	RiCOPTER	Lidar + RGB	Transect	60
6/23/2017	12:30	31	RiCOPTER	Lidar + RGB	Transect	30
6/23/2017	15:33	30	RiCOPTER	Lidar + RGB	Hover	20

ERDC-CHL-FRF						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/6/2017	13:50	6	DJI Phantom 4 Pro	RGB	Canvas	80
6/6/2017	15:45	4	DJI Phantom 4 Pro	RGB	Canvas	80
6/13/2017	13:33	10	DJI Phantom 4 Pro	RGB	Hover	100
6/13/2017	15:09	4	DJI Phantom 4 Pro	RGB	Hover	100
6/13/2017	14:29	10	DJI Phantom 4 Pro	RGB	Hover	100
6/13/2017	14:04	10	DJI Phantom 4 Pro	RGB	Hover	100
6/14/2017	15:57	8	DJI Phantom 4 Pro	RGB	Hover	352
6/15/2017	12:24	3	DJI Phantom 4 Pro	RGB	Hover	18
6/15/2017	16:05	3	DJI Phantom 4 Pro	RGB	Transect	100
6/15/2017	15:58	3	DJI Phantom 4 Pro	RGB	Transect	100
6/28/2017	16:24	12	DJI Phantom 4 Pro	RGB	Canvas	100
6/28/2017	16:00	12	DJI Phantom 4 Pro	RGB	Canvas	100
6/9/2017	14:50	14	Modified 3DR X8+	Multi-RGB	Transect	100
6/9/2017	10:07	6	Modified 3DR X8+	Multi -RGB	Canvas	50
6/13/2017	11:30	14	Modified 3DR X8+	Multi -RGB	Transect	100
6/13/2017	16:20	14	Modified 3DR X8+	Multi -RGB	Transect	50
6/14/2017	9:39	11	Modified 3DR X8+	Multi -RGB	Canvas	50
6/14/2017	10:01	8	Modified 3DR X8+	Multi -RGB	Canvas	100
6/14/2017	16:38	11	Modified 3DR X8+	Multi -RGB	Canvas	100
6/14/2017	17:21	6	Modified 3DR X8+	Multi -RGB	Transect	100

ERDC-CHL-FRF						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/14/2017	14:45	10	Modified 3DR X8+	Multi -RGB	Transect	100
6/14/2017	15:10	10	Modified 3DR X8+	Multi -RGB	Transect	100
6/14/2017	15:49	10	Modified 3DR X8+	Multi -RGB	Transect	100
ERDC-EL						
6/19/2017	11:39	11	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/19/2017	12:20	12	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/19/2017	13:23	16:20	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/19/2017	14:02	14	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/19/2017	15:13	15	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/19/2017	17:11	16	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/20/2017	11:33	11	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/20/2017	11:48	11	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/20/2017	12:39	14	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/20/2017	13:52	18	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/20/2017	14:32	21	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/21/2017	N/A	13	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/21/2017	N/A	13	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/21/2017	N/A	9	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/21/2017	17:25	14	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/21/2017	18:00	12	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	8:52	13	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	9:54	13	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	10:23	14	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	22:55	14	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	23:24	14	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	12:13	10	Skycrane	RGB + IR+ MultiSpec	Canvas	60
6/22/2017	13:11	9	Skycrane	Lidar + Hyperspec	Canvas	60
6/22/2017	13:56	12	Skycrane	Lidar + Hyperspec	Canvas	60
6/22/2017	15:15	9	Skycrane	Lidar + Hyperspec	Canvas	60
6/22/2017	15:42	11	Skycrane	Lidar + Hyperspec	Canvas	60

ERDC-EL						
Date	Time (Local ESDT)	Duration (min)	Platform	Sensor Type	Flight Type	Elevation (m)
6/22/2017	16:20	11	Skycrane	Lidar + Hyperspec	Canvas	60
6/23/2017	9:50	11	Skycrane	Lidar + Hyperspecl	Canvas	60
6/23/2017	10:21	12	Skycrane	Lidar + Hyperspec	Canvas	60
6/23/2017	11:44	12	Skycrane	Lidar + Hyperspec	Canvas	60
6/23/2017	13:08	12	Skycrane	Lidar + Hyperspec	Canvas	60
6/23/2017	14:08	11	Skycrane	Lidar + Hyperspec	Hover	60
6/23/2017	16:30	12	Skycrane	Lidar + Hyperspec	Hover	60
ERDC-GRL						
6/6/2017	9:17	18	SenseFly EBee	NIR	Canvas	100
6/6/2017	10:22	23	SenseFly EBee	Multispectral	Canvas	120
6/6/2017	10:55	7	SenseFly EBee	Multispectral	Canvas	120
6/6/2017	11:50	25	SenseFly EBee	Multispectral	Canvas	150
6/5/2017	13:14	22	SenseFly EBee	Thermal	Canvas	150
6/5/2017	13:59	18	SenseFly EBee	Thermal	Canvas	150
6/5/2017	12:03	11	SenseFly EBee	RGB	Canvas	100
6/5/2017	12:29	23	SenseFly EBee	RGB	Canvas	100
6/5/2017	11:10	15	SenseFly EBee	RGB	Canvas	70
6/5/2017	11:32	11	SenseFly EBee	RGB	Canvas	70
6/6/2017	12:35	25	SenseFly EBee	RGB	Canvas	100
6/6/2017	1:15	10	SenseFly EBee	RGB	Canvas	100
6/7/2017	9:42	12	SenseFly EBee	RGB	Canvas	70
6/7/2017	10:02	9	SenseFly EBee	RGB	Canvas	70
6/9/2017	9:10	32	SenseFly EBee	RGB	Canvas	100
6/9/2017	10:02	22	SenseFly EBee	RGB	Canvas	70
VCU/ERDC-GRL						
6/15/2017	14:46	25	3DRSolo	RGB	Canvas	80
6/15/2017	14:04	6	3DRSolo	RGB	Canvas	80
6/17/2017	13:50	35	Sky-Watch Cumulus	RGB	Canvas	110
6/17/2017	14:53	19	Sky-Watch Cumulus	RGB	Canvas	75